Paths to Clean Vehicle Technology and Alternative Fuels Implementation in San Bernardino County

Task 3: Analysis of Alternative Paths to Clean Vehicle and Fuels Implementation

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1 Introduction

This report describes the analysis of alternatives paths to implementation of clean vehicles and fuels in San Bernardino County. The overall purpose of this study is to explore ways that local and regional agencies and the private sector can accelerate the penetration of clean vehicle and fuel technologies. The goal is to identify technology pathways that will enable San Bernardino County to improve air quality and reduce greenhouse gas emissions while also supporting local and regional economic goals.

The study considers both existing and emerging strategies for all types of on-road vehicles, including:

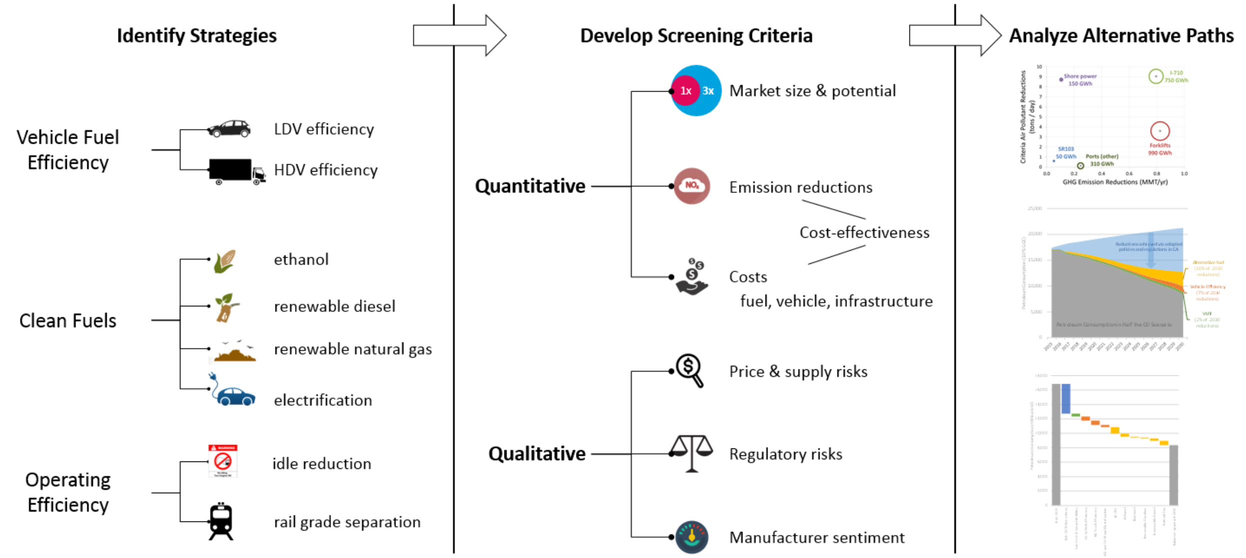
- Improved vehicle fuel efficiency
- Electric and fuel cell vehicles
- Natural gas vehicles
- Biofuels

The results of the study are intended to provide local and regional agencies with solutions to help overcome barriers to cleaner vehicles and fuels and maximize the benefits of clean transportation for the San Bernardino County economy.

Sections 2 and 3 of this report present an assessment of the technology and fuel options under consideration, with Section 2 focused on light duty vehicles and Section 3 focused on heavy duty vehicles.

Sections 4 and 5 describe the development of scenarios and analysis of results. The analysis is conducted using an Excel-based dynamic tool that enables project stakeholders to analyze alternative paths for achieving emission reduction goals. The analytical tool considers individual strategies for different vehicles and fuel types—using metrics such as cost, emissions reductions, and emission reduction cost-effectiveness. Each alternative path or scenario for clean vehicle and fuels implementation is built up using a series of technology-specific strategies.

Each individual strategy is assessed using quantitative and qualitative criteria. Selected strategies are bundled into alternative paths (scenarios) that are reflective of defining characteristics developed in collaboration with the San Bernardino County Transportation Authority (SBCTA), Southern California Association of Governments (SCAG), and the project Technical Advisory Committee (TAC). The figure below illustrates in a general sense the process for identifying strategies, developing and applying screening criteria, and analyzing alternative paths.



The final task in this project will be to use the results of the stakeholder outreach and the analysis to develop a set of products that are accessible to local and regional government agencies and clearly communicate the opportunities for each type of stakeholder to support clean vehicle and fuel strategies. The work steps involved in this final task include:

1) Identify the challenges and barriers associated with each alternative path. These challenges could be related to equipment cost, fuel cost, technological feasibility, vehicle performance, consumer acceptance, fueling infrastructure, fuel supply, electricity supply, regional and local agency funding constraints, or many other factors.

2) Develop strategies for overcoming the challenges and barriers identified in step 1, with particular attention on implementation actions that can involve Southern California local and regional agencies and private sector partners. This task will also identify implementation strategies that would be led by state or federal agencies, recognizing that local and regional agencies could help to promote the implementation of state or federal actions through advocacy and partnerships.

3) Organize and summarize the implementation strategies developed in step 2 into a set of recommendations for each type of stakeholder, including federal and state agencies, regional agencies (South Coast Air Quality Management District (AQMD), SCAG, etc.), local agencies (cities and counties), utilities, fleet owners, developers, fuel infrastructure provides, and others. This information will be compiled into an Action Plan. The Action Plan will be a high-level document with attractive, full color formatting and graphics – designed to be accessible to senior leaders, elected officials, and other decision makers who may not be interested in the details of the study analytical work.

A Final Report will document all the work conducted during the project.

2 Assessment of Technology and Fuel Options – Light Duty Vehicles

This section describes clean vehicle technology and fuel options for light duty vehicles. The options are organized into two sub-sections: vehicle efficiency improvements (using conventional fuels) and clean fuels. Each option is discussed in terms of technology readiness, emissions impacts, vehicle costs, and infrastructure costs.

2.1 Vehicle Efficiency Improvements

Expand Fuel Economy Regulations

Technology Readiness

Fuel economy standards have been around since the 1970s for light-duty vehicles and have contributed to significant reductions in petroleum use and fuel costs for consumers. California, under the Clean Air Act, has unique authority to set emissions standards for vehicles that are more stringent than national standards, which 13 states and the District of Columbia currently follow. In 2010, the U.S. Environmental Protection Agency (EPA) and the National Highway Traffic Safety Administration (NHTSA) harmonized their emissions and fuel economy standards with California's program to create a new, two-phase National Program. Phase 1 covered vehicle model years 2012-2016 with an average fuel economy target of 34.1 mpg for model year 2016, and Phase 2 covered model years 2017-2025 with an average fuel economy target of 54.5 mpg for model year 2025 if standards were met solely with fuel efficiency improvements.[1] The standards were subject to a mid-term evaluation in 2016, which concluded in a Final Determination that the original standards developed for model years 2022-2025 were feasible and appropriate.[2] In April 2018, the U.S. EPA declared it would reconsider the findings of the mid-term evaluation and in August, 2018, U.S. EPA and NHTSA issued the Safe Affordable Fuel Efficient Vehicles Proposed Rule for model years 2021-2026, which notably weakens the standards established under the original Phase 2 program.[3] The new Proposed Rule has not been adopted and would likely face litigation upon finalization, resulting in potential further regulatory uncertainty for automakers.

In its Final Determination of the mid-term evaluation on the appropriateness of fuel economy and greenhouse gas (GHG) emission standards for the later years of the Phase 2 program, U.S. EPA found that automakers had largely over-complied with the standards during the first four years of Phase 1, and that the industry had amassed a significant number of banked credits from these early years.[4] This finding demonstrates that automakers have the capability to deploy technologies at scale that lower emissions and exceed fuel economy standards. Moreover, the Phase 2 standards provide the flexibility

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[1] According to Union of Concerned Scientists, given the compliance flexibility built into the standards, average fuel economy of new cars in 2025 is expected to be closer to 37 mpg. For comparison, on-road fleet fuel economy was 21 mpg in 2017. https://www.ucsusa.org/clean-vehicles/fuel-efficiency/fuel-economy-basics.html

[2] https://www.epa.gov/regulations-emissions-vehicles-and-engines/midterm-evaluation-light-duty-vehicle-greenhouse-gas

[3] https://www.epa.gov/regulations-emissions-vehicles-and-engines/safer-affordable-fuel-efficient-safe-vehicles-proposed

[4] https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100QQ91.pdf

for automakers to pursue multiple technology pathways to achieve compliance as the standards gradually tighten. For example, the Final Determination outlines a number of engine, transmission, and vehicle technologies and their estimated model year 2025 penetration rates (expressed as percentages below) that can be employed to achieve the standards, including turbocharged engines (31-41%), naturally aspirated gasoline engines (5-41%), advanced transmissions (92-94%), mass reduction (2-10%), stop-start idling technology (12-39%), and mild hybrids (16-27%).[5] All of these technologies are readily available today at commercial scale.

U.S. EPA and the California Air Resources Board (CARB) also regulate other vehicle emissions beyond GHGs. In 2014, US finalized “Tier 3” fuel and vehicle standards that would come into effect in 2017 to reduce criteria pollutant emissions.[6] The standards follow the implementation of Tier 2 standards, which were finalized in 2000, and cover evaporative and tailpipe emissions from nitrogen oxides, volatile organic compounds, particulate matter, carbon monoxide, and air toxics. The standards also lower the sulfur content in gasoline. In order to meet the standards, automakers need to improve emission control technologies such as catalytic converters. The Tier 3 Final Rule clearly states that the standards are feasible across all regulated fleets, and the standards are harmonized with CARB Low Emission Vehicle (LEV III) standards.[7]

Emissions Impacts

Emissions reductions attributable to light-duty fuel economy and GHG standards have been significant. The National Program (Phase 1 and Phase 2) were projected to avoid 6 billion metric tons of carbon dioxide pollution and cut oil consumption by 12 billion barrels over the lifetime of model year 2012-2025 vehicles.[8] Measures of actual emission reductions attributable to this program are not readily available, in part due to EPA’s recent decision to roll back the Phase 2 standards. EPA’s most recent Automotive Trends report shows that real-world fuel economy reached a new high in 2018 while fleet-average GHG emission rates reached a new low, as shown in the figure below.

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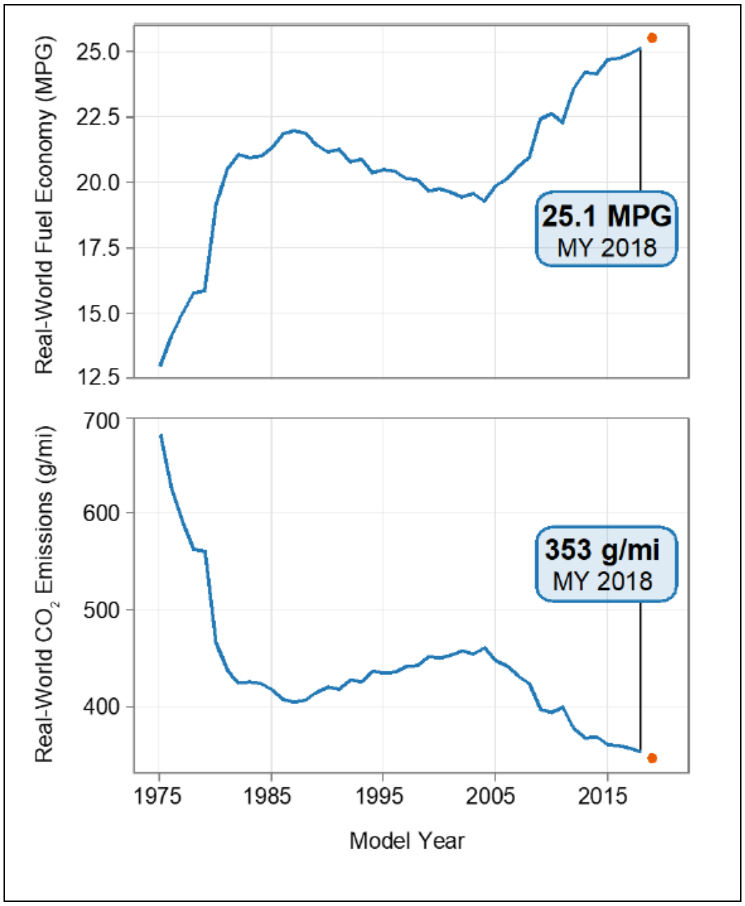
[5] https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100QQ91.pdf

[6] https://nepis.epa.gov/Exe/ZyPDF.cgi/P100HVZV.PDF?Dockey=P100HVZV.PDF

[7] https://www.govinfo.gov/content/pkg/FR-2014-04-28/pdf/2014-06954.pdf

[8] https://www.nhtsa.gov/staticfiles/rulemaking/pdf/cafe/Draft-TAR-Final-Executive-Summary.pdf

Figure 1. Real-World U.S. Vehicle Fuel Economy and GHG Emission Rates Through 2018



Source: U.S. EPA, *The 2019 EPA Automotive Trends Report*, EPA-420-R-20-006, March 2020.

The Tier 3 emissions standards are also expected to significantly reduce criteria pollutant emissions from on-road vehicles. By 2030, annual emissions reductions would amount to: 328,509 tons of Nitrogen Oxide (NOx), 167,591 tons of volatile organic compounds, 3,458,041 tons of carbon monoxide, 7,892 tons of particulate matter (2.5), and 12,399 tons of sulfur dioxide, among other pollutants and air toxics.[9]

Vehicle Costs

In its Final Determination, U.S. EPA found that the incremental per vehicle costs of meeting model year 2022-2025 standards were approximately $1,100, or $36 billion in aggregate across the industry.[10] However, the net consumer fuel cost savings realized as a result of fuel economy improvements were

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[9] It's important to note that these standards also regulate some medium- and heavy-duty vehicles, so not all emissions reductions from Tier 3 standards are attributable to light-duty vehicles. https://nepis.epa.gov/Exe/ZyPDF.cgi/P100HVZV.PDF?Dockey=P100HVZV.PDF

[10] https://fas.org/sgp/crs/misc/R45204.pdf

projected to be $1,500 per vehicle, with total projected consumer pre-tax fuel savings amounting to $89 billion.[11]

U.S. EPA estimates the cost of the Tier 3 standards will cost less than a penny per gallon of gasoline, or about $72 per vehicle.[12] This translates to an annual overall program cost of $1.5 billion in 2030, with annual monetized health benefits amounting to $6.7-$19 billion.

Although increasingly-stringent fuel economy and emissions standards require investment and commercialization of new technologies with short-term costs, standards have proven to help reduce petroleum consumption, lower GHG and other air pollutant emissions, save drivers money on fuel costs, and provide ancillary health benefits.

Infrastructure Costs

While there may be some incremental infrastructure costs associated with achieving compliance with Tier 3 fuel sulfur standards for refiners, fuel economy standards do not require the deployment of additional infrastructure.

Fleet Turnover Incentives

Technology Readiness

Fleet turnover incentives can help encourage consumers and fleet operators to retire fuel-inefficient vehicles in favor of newer, more efficient ones. These incentives can be monetary or non-monetary and include purchase rebates, scrappage rebates, income tax credits, HOV lane access, and parking fee exemptions.[13] At the federal level, the Car Allowance Rebate System (also known as CARS or 'Cash-for-Clunkers') was signed into law in 2009 and ran from July to August of 2009.[14] California implements its own vehicle retirement program, the Consumer Assistance Program, which is administered by the Bureau of Automotive Repair.[15]

Turnover incentives do not require any technological readiness, though the impact of these incentives will depend on difference in performance of the vehicles retired compared to the performance of new vehicles incentivized as a result of the program. Therefore, it's inferred that technological improvements have occurred between vehicles that are retired early and vehicles that are eligible for incentives.

Emissions Impacts

Estimating emissions impacts of turnover incentives is challenging because it requires the establishment of a counterfactual or baseline from which reductions are measured. Two different studies from 2013 estimate that the 2009 CARS program reduced carbon dioxide emissions by 4.4 million tons and 25-27

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[11] *Id.*

[12] https://nepis.epa.gov/Exe/ZyPDF.cgi/P100HVZV.PDF?Dockey=P100HVZV.PDF

[13] https://www.arb.ca.gov/cc/sb375/policies/flttrnovr/fleet_turnover_brief.pdf

[14] https://obamawhitehouse.archives.gov/blog/2010/04/05/did-cash-clunkers-work-intended

[15] https://www.bar.ca.gov/Consumer/Consumer_Assistance_Program/CAP_Vehicle_Retirement_Program.html

million tons.[16] California's Consumer Assistance Program reduced emissions an estimated 7,000 tons during fiscal year 2016-2017.[17]

Vehicle Costs & Infrastructure Costs

There are no direct vehicle or infrastructure costs associated with fleet turnover incentives.

Fuel Efficient Tires

Technology Readiness

Approximately 4-11% of light-duty vehicle fuel consumption is attributed to overcoming rolling resistance, which can be expressed as a dimensionless coefficient.[18] Low rolling resistance tires reduce the amount of energy lost from drag and friction, and a 10% reduction in rolling resistance could improve fuel economy by 1-2%.[19] Most new vehicles are already equipped with low rolling resistance tires; however, there are no requirements in place to ensure the efficiency of replacement tires and consumers have limited access to information on rolling resistance when making tire purchase decisions.[20] Replacement tires vary widely in terms of rolling resistance performances, with the least efficient tires producing 25% more rolling resistance than the most efficient ones.[21]

Improvements to tires' rolling resistance should not compromise other aspects of tire performance. Despite concerns that lower rolling resistance would sacrifice tire traction, the U.S. National Research Council has not found significant differences in rolling resistance of tires with similar traction grades.[22] Silica can also be used to improve rolling resistance without sacrificing traction. Studies have also found no robust correlation between tire rolling resistance and tire wear. Ensuring tires are properly inflated can improve both efficiency and durability.

Overall, while fuel-efficient replacement tires are commercially available, there are still consumer information and marketing gaps that must be overcome to increase adoption of low rolling resistance tires.

Emissions Impacts

In aggregate, the emissions impacts of low rolling resistance tires can be significant. According to a 2010 International Council on Clean Transportation (ICCT) report, modest and technically feasible tire improvements could reduce fuel consumption by 3-5% and reduce GHG emissions by an estimated 100 million metric tons per year globally in 2020.[23] These improvements would also mitigate 45,000 metric

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[16] https://www.arb.ca.gov/cc/sb375/policies/flttrnovr/fleet_turnover_brief.pdf
[17] https://www.bar.ca.gov/Consumer/Consumer_Assistance_Program/CAP_Vehicle_Retirement_Program.html
[18] https://afdc.energy.gov/conserve/fuel_economy_tires_light.html
[19] https://www.theicct.org/sites/default/files/publications/ICCT_tireefficiency_jun2011.pdf
[20] Consumer Reports offers ratings that compare tires based on rolling resistance and overall performance, but this information is only accessible to Consumer Reports members. https://www.consumerreports.org/cro/2012/12/low-rolling-resistance-tires/index.htm
[21] https://www.edmunds.com/fuel-economy/resistance-movement.html
[22] https://www.theicct.org/sites/default/files/publications/ICCT_tireefficiency_jun2011.pdf
[23] *Id.*

tons of nitrogen oxides and 10,000 metric tons of particulate matter emissions annually. A University of Michigan study found that based on average light-duty vehicle miles traveled data, switching from the worst- to best-performing tires could save approximately 32 gallons annually – equivalent to roughly 750 pounds of GHG emissions per vehicle.

Vehicle Costs

Producing tires that achieve noticeable fuel economy improvements require relatively modest cost increases. U.S. EPA estimated that improving rolling resistance in tires by 10% would cost $6 per vehicle, while the National Research Council estimated that similar improvements would cost $2-$5 per tire for new cars.[24] Fuel cost savings from tire improvements will depend on the price of gasoline and the distance the vehicles are traveled; switching from high to low rolling resistance tires could save approximately $78 annually in fuel costs, based on gasoline prices at $2.43 per gallon.[25] Savings will increase as gasoline costs rise.

Infrastructure Costs

There are no infrastructure costs directly related to low-rolling resistance tires.

2.2 Clean Fuels

Higher Blends of Ethanol

Technology Readiness

Ethanol is produced from corn or cellulosic feedstocks, such as crop residues and wood. Starch- and sugar-based ethanol is produced via dry-milling or wet-milling, and cellulosic production can be achieved through biochemical or thermochemical pathways. E10, a blend of 10% ethanol and 90% gasoline, is required for light-duty vehicles in California (E10 is referred to as reformulated gasoline; the gasoline and ethanol formulation helps to reduce harmful criteria pollutant emissions). E15 is a blend of 0.5%-15% ethanol with gasoline and is approved for use in model year 2001 and newer light-duty conventional gas vehicles. E85, sometimes known as flex fuel, is an ethanol blend containing 51%-83% ethanol and is only for use in flex fuel vehicles. Ethanol is produced at facilities across the Midwest, Southern US, and Western states, and there are 6 ethanol production facilities in California. Most ethanol consumed in California is via E10, although there has been growth in E85 consumption as well, with E85 retail stations increasing from 30 to more than 150 between 2009 and 2018. Ethanol consumption has shifted to ethanol with lower carbon intensity rather than increased as a whole.

Flex fuel vehicles (FFVs), which can operate on E85, gasoline, or a blend of the two, are widely available as a standard option for many light-duty vehicle models. FFVs are very similar to conventional gasoline vehicles, and have improved acceleration performance when operating on higher ethanol blends.

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[24] *Id.*

[25] https://www.consumerreports.org/fuel-economy/low-rolling-resistance-tires-can-save-fuel/

Emissions Impacts

On a life cycle basis, ethanol produced from corn reduces GHG emissions by about 30%. Ethanol produced with cellulosic feedstocks can reduce GHG emissions from 50%-90% when land-use change emissions are considered.

Ethanol is predominantly produced using corn. However, ethanol producers are now seeking to reduce their carbon intensity, and the carbon intensity of ethanol has decreased steadily over time. Older facilities with high carbon intensity were nearly phased out by the end of 2017; ethanol with carbon intensity higher than 75 g/MJ was reduced from nearly 90% of the ethanol low carbon fuel standard (LCFS) credits in 2011 to less than 5% in 2018.

Vehicle Costs

Flex fuel vehicles are available at comparable prices to gasoline vehicles, and there is not an incremental cost associated with flex fuel vehicles, though manufacturers likely face a per vehicle cost of roughly $50-100.

Infrastructure Costs

E85 fueling infrastructure costs vary widely by project. Stations can add E85 equipment by converting an existing tank or adding a new tank and retrofitting or adding new dispensers. A 2008 survey of 120 E85 stations by the National Renewable Energy Laboratory found that costs ranged from $7,599-$247,600 for a new tank and $1,736-$68,000 for an existing tank.[26]

Renewable Gasoline

Technology Readiness

Renewable gasoline is a drop-in fuel that meets the ASTM D484 specification. (ASTM International, formerly known as American Society for Testing and Materials, is an international standards organization that develops and publishes voluntary consensus technical standards for a wide range of materials, products, systems, and services. ATSM establishes standards for fuels used in motor vehicles that are widely recognized by manufacturers and fuel suppliers.) Renewable gasoline is made from biomass feedstocks.

Renewable gasoline is not commercially available at this time.

Emissions Impacts

The emissions impacts of renewable gasoline are still being studied.

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[26] National Renewable Energy Laboratory. Cost of Adding E85 Fueling Capability to Existing Gasoline Stations: NREL Survey and Literature Search. https://afdc.energy.gov/files/pdfs/42390.pdf.

Vehicle Costs

Because renewable gasoline is a drop-in fuel, there is no vehicle incremental cost associated with the use of renewable gasoline.

Infrastructure Costs

Because renewable gasoline is a drop-in fuel, it can use existing gasoline fueling infrastructure.

Plug-in Electric Vehicles

Technology Readiness

Plug-in electric vehicles (EVs) are now widely commercially available and offer a promising alternative to gasoline and diesel-powered light-duty vehicles. EVs are typically broken out into two distinct architectures: plug-in hybrid electric vehicles (PHEVs) use a battery and internal combustion engine for propulsion while battery electric vehicles (BEVs) rely solely on a battery. Over 1.2 million EVs have been sold in the U.S., with nearly half of those sales occurring in California.[27] Although EVs were initially limited to smaller vehicle body types, electric SUVs and trucks are either already being sold or are under development: Kia, Hyundai, Subaru, Volvo, Tesla, and Jaguar have recently introduced all-electric SUVs and crossover vehicles in California while automakers like Ford, Tesla, and Rivian are developing electric pick-up trucks for sale in the next several years.[28][29] There are approximately 60 EV models available today in the U.S. and that number is expected to increase to over 100 by 2022, giving consumers more choice and flexibility in EV purchase decisions.[30] Over 360,000 EVs were sold nationally in 2018 (about 2% of total light-duty sales) and that figure is expected to grow.[31] Edison Electric Institute recently developed a forecast, based on five independent forecasts, that predicts annual EV sales will reach 3.5 million and cumulative sales will surpass 18 million vehicles in the U.S. by 2030.[32] Bloomberg New Energy Finance anticipates EVs will comprise 55% of new car sales and a third of the vehicle fleet globally by 2040.[33] California and 9 other states that have adopted California's Zero Emissions Vehicle (ZEV) program have been coordinating to reach a cumulative 3.3 million ZEV sales goal by 2025, which will primarily be met with EVs.[34] California, via executive order B-48-18, has targets that put the state on the path toward 1.5 million EVs by 2025 and 5 million EVs by 2030.[35]

Most BEVs today do not have ranges comparable to their internal combustion engine counterparts. However, improvements in battery technology are increasing vehicle range: the Department of Energy

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[27] https://www.veloz.org/sales-dashboard/

[28] https://cleanvehiclerebate.org/eng/eligible-vehicles

[29] http://fortune.com/2019/04/25/ford-is-making-its-own-electric-truck-so-why-is-it-investing-in-rivian/

[30] http://eprijournal.com/electric-vehicle-market-revs-up/

[31] https://www.greentechmedia.com/articles/read/us-electric-vehicle-sales-increase-by-81-in-2018#gs.b6s9ku

[32] http://www.edisonfoundation.net/iei/publications/Documents/IEI_EEI%20EV%20Forecast%20Report_Nov2018.pdf

[33] https://about.bnef.com/electric-vehicle-outlook/#toc-download

[34] https://www.zevstates.us/

[35] http://www.opr.ca.gov/planning/transportation/zev.html

found that the median range of new BEVs increased from 73 to 125 miles from 2011 to 2018.[36] Moreover, many new BEVs have ranges exceeding 200 miles, including but not limited to: the Chevrolet Bolt (248 miles), Nissan LEAF PLUS (226 miles), Hyundai Kona (258 miles), and Tesla Model 3 (220+ miles). Given that motorists drive, on average, approximately 12,000 to 15,000 miles per year, EVs are well-suited to handling daily driving needs of most drivers between charges. Less frequent and longer-distance trips are still feasible in some situations, though concerns persist about the availability of public charging infrastructure – particularly fast-charging infrastructure.[37] About 80% of EV charging takes place at home, typically overnight when the vehicle is parked.[38] However, lack of charging infrastructure is one of the key challenges associated with the widespread use of EVs; as the EV market continues to grow, more public and workplace charging infrastructure will be needed to support EV adoption for drivers without dedicated access to residential charging.

Emissions Impacts

BEVs and PHEVs produce zero tailpipe emissions when running on electricity. PHEVs produce emissions when using their gasoline engines, but are generally more fuel-efficient than the average internal combustion engine vehicle. Well-to-wheels emissions, which include emissions from fuel production and fuel use, are dependent on the regional electric generation mix. California's grid is one of the cleanest in the nation: 29 percent of California's power mix came from renewable generation in 2017 – not including large hydro.[39] On this generation mix, EVs produce 81% less GHG emissions than a comparable gasoline vehicle.[40] Moreover, Governor Brown signed Senate Bill 100 in 2018, which ramps up the state's Renewable Portfolio Standard requirements to 60% by 2030 and 100% by 2045.[41] Therefore, as the state and regional electricity systems get cleaner, light-duty EV well-to-wheels emissions will continue to decline. Based on 2018 data, Union of Concerned Scientists (UCS) found that EVs on California's electric grid produce GHG emissions equivalent to a car with a fuel economy rating of 109 MPG, up from 78 MPG in 2009.[42] Natural Resources Defense Council (NRDC) and Electric Power Research Institute (EPRI) found that in a scenario with a significantly decarbonized power system and widespread EV adoption (including some medium- and heavy-duty electrification), national transportation sector emissions were reduced by 550 million tons annually in 2050.[43] Because of their low carbon attributes, EVs are expected to be a critical pathway to achieving economy-wide deep decarbonization. The California Energy Commission (CEC) estimates that in order to meet state decarbonization targets in 2030 and 2050, 60% of new light-duty vehicle sales need to be EVs in 2030.[44]

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[36] https://www.energy.gov/eere/vehicles/articles/fotw-1064-january-14-2019-median-all-electric-vehicle-range-grew-73-miles

[37] https://www.fhwa.dot.gov/ohim/onh00/bar8.htm

[38] https://www.energy.gov/eere/electricvehicles/charging-home

[39] https://www.energy.ca.gov/almanac/electricity_data/total_system_power.html

[40] https://afdc.energy.gov/vehicles/electric_emissions.html

[41] https://www.energy.ca.gov/renewables/

[42] https://blog.ucsusa.org/dave-reichmuth/new-data-show-electric-vehicles-continue-to-get-cleaner

[43] http://epri.co/3002006881

[44] https://www.ethree.com/wp-content/uploads/2018/06/Deep_Decarbonization_in_a_High_Renewables_Future_CEC-500-2018-012-1.pdf

Vehicle Costs

EVs are still more expensive than their gasoline counterparts on an upfront cost basis before incentives, which is largely due to the cost of the battery. However, battery costs are continuing to decline: in 2015, a battery represented roughly 57% of an EV's total cost, and that figure has dropped to 36% in 2018.[45] Put differently, average EV battery costs declined from $373/kilowatt-hour (kWh) in 2015 to $176/kWh in 2018 and are expected to decline to $94/kWh in 2024, at which point some analysts believe EVs will largely achieve upfront cost parity with internal combustion engine (ICE) vehicles.[46] Other reports have generally suggested more conservative costs by the middle of next decade ($120-$140/kWh).[47] Other EV powertrain equipment beyond the battery will continue to decline in cost by approximately 10% between 2017 and 2025.[48] On a total cost of ownership basis, some EVs may already be competitive with similar ICE models given the superior battery efficiency and low maintenance costs of EVs. Fuel cost savings can be significant, particularly when drivers can take advantage of time-varying electricity rates that lower the cost of fuel during off-peak times when the grid is not stressed. In California, the average price of an eGallon (gallon of gasoline equivalent for EVs) is $1.80 compared to $3.95 a gallon for regular gasoline.[49] ICCT estimates that EV owners could expect to realize fuel savings of $3,500 for cars, $3,900 for crossovers, and $4,200 for SUVs over the first 5 years of ownership, and when comparing the first 5 years of ownership costs, many EVs will be more attractive than ICE models as early as 2022 and even earlier on a 10-year ownership basis.[50]

Infrastructure Costs

Light-duty EVs can refuel with different types of charging infrastructure at a diverse array of sites. Level 1 charging stations use a standard 120V outlet and provide about 1.1 kilowatts (kW) of power, refueling an EV at a rate of 2-5 miles per hour of charging. Level 1 stations are typically deployed at locations where vehicles are parked for long periods of time, such as homes, workplaces, and airports. A simple Level 1 cord-set can cost as low as $300 and is suitable for home use, but pedestal units that are more appropriate for parking lots can cost up to $1,500 per unit.[51] Level 1 stations are typically non-networked, meaning that they cannot send data to a network operator.

Level 2 stations use a 208V/240V outlet and typically provide 3.3-6.6 kW of power, providing 10-20 miles of range per hour of charging. Level 2 stations are also deployed at locations where vehicles dwell for longer periods of time, including homes, workplaces, and other overnight locations. Level 2 units may cost as low as $400 for basic, non-networked stations that may be appropriate for home use. However, for workplace and public networked Level 2 stations that require a pedestal, units can cost up to $6,000.[52]

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[45] https://www.bloomberg.com/opinion/articles/2019-04-12/electric-vehicle-battery-shrinks-and-so-does-the-total-cost

[46] https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/

[47] https://www.theicct.org/sites/default/files/publications/EV_cost_2020_2030_20190401.pdf

[48] https://www.theicct.org/sites/default/files/publications/EV_cost_2020_2030_20190401.pdf

[49] Accessed May 13, 2019. https://www.energy.gov/eere/electricvehicles/saving-fuel-and-vehicle-costs

[50] https://www.theicct.org/sites/default/files/publications/EV_cost_2020_2030_20190401.pdf

[51] https://afdc.energy.gov/files/u/publication/evse_cost_report_2015.pdf

[52] *Id.*

Direct Current Fast Charging (DCFC) stations require 480V service and current stations provide power at 25 kW up to 350 kW, although most installed DCFC stations provide 50 kW of power.[53] These 50 kW plugs can add over 3 miles of range per minute, while 350 kW connectors can add 20 mile per minute. DCFC stations are installed in public locations where cars may only be parked a short while or where electric shared mobility (i.e. car-sharing, ride-hailing, etc.) fleets can easily access them.[54] DCFC station costs are significant: 50 kW units cost roughly $50,000 and 150-350 kW units can be significantly more expensive.[55]

Installation costs for all three types of infrastructure vary widely and are dependent on charging station power levels and site specific conditions. Installation cost drivers include but are not limited to: permitting, electricity metering, electrical supply conduit, trenching and boring to lay conduit, and upgrading electrical panels. Level 1 installation costs are relatively modest, with wall-mounted Level 1 costs around $300-$1,000 and pedestal-mounted units costing $1,000-$3,000.[56] Level 2 installation costs vary widely: average costs hover around $3,000 per station but have been as high as $12,000.[57] DCFC installation costs also exhibit variability, with 50 kW stations averaging roughly $25,000 per installation but often surpassing $40,000 per installation in areas that require significant electrical upgrades.[58] Higher capacity DCFC station installations will likely drive costs upward.

Charging stations also incur operations and maintenance (O&M) costs that vary by charger type and location. On top of hardware component replacements and electricity costs (which may be passed on to EV drivers in some cases), networked stations also carry networking fees that can range from $100-$900 annually.[59] Routine maintenance is typically more crucial for DCFC stations, which have more components than Level 1 or 2 stations and are relied upon in key refueling situations (e.g. highway corridor charging).

At current levels of EV adoption and in most cases, it is extremely challenging to make a compelling economic case to deploy EV charging solely based on charging fees for EV charging services ("charging for charging"). For that reason, many charging stations have been deployed with government or utility incentives or deployed as an amenity. As EV adoption and demand for charging stations increase, more private capital may be leveraged to deploy EV charging stations.

Fuel Cell Vehicles

Technology Readiness

Similar to EVs, fuel cell vehicles (FCVs) use electricity to power an electric motor. However, the electricity instead comes from stored hydrogen gas that passes through a fuel cell that generates an electric current by splitting hydrogen molecules into electrons and protons.[60] Light-duty FCVs are

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[53] Only BEVs can charge at DCFC stations.

[54] These stations are also critical for enabling long distance EV travel on highway corridors

[55] http://www.caletc.com/wp-content/uploads/2019/01/Literature-Review_Final_December_2018.pdf

[56] https://afdc.energy.gov/files/u/publication/WPCC_L1ChargingAtTheWorkplace_0716.pdf

[57] https://afdc.energy.gov/files/u/publication/evse_cost_report_2015.pdf

[58] *Id.*

[59] *Id.*

[60] http://www.fchea.org/fuelcells

commercially available but have not been deployed to the same degree as light-duty EVs. As of May 2019, about 6,500 FCVs were sold or leased in the US.[61] Given that California has the most operational hydrogen fueling stations in the US, it can be inferred that the bulk of FCVs reside in California.[62] The California Energy Commission (CEC) also expects the number of FCVs in the state to increase to 13,400 in 2020 and 37,400 by 2023.[63] There are currently 4 light-duty FCV models eligible for California's Clean Vehicle Rebate, including two SUV models from Hyundai.[64] These vehicles have ranges and refueling times comparable to ICE vehicles, meaning that the technology does not require significant consumer adaptation for their use.

The challenge with widespread deployment of FCVs is related less to the vehicles and more to the infrastructure needed to fuel them. Currently, there are only 40 public hydrogen fueling stations available in the U.S., and all of them are in California; moreover, the U.S. Department of Energy's (DOE) Alternative Fuels Data Center identifies 24 planned (yet to be operational) stations nationwide, which includes a small Northeastern corridor from New York to Massachusetts.[65] California has a goal to deploy 100 hydrogen refueling stations statewide by 2022, and upon completing the deployment of 65 operational stations, some of which are currently in development, CEC estimates that California will have the hydrogen capacity to support 21,000 light-duty FCVs.[66] Without sustained investments in refueling infrastructure, it is unlikely that the FCV will reach a scale needed to displace significant numbers of ICE vehicles.

Emissions Impacts

FCVs produce zero tailpipe emissions. Like electricity for EVs, hydrogen for FCVs can be produced from a number of processes and sources which impacts FCVs' well-to-wheels emissions. The most common process is natural gas reforming, which involves the use methane and thermal processes to create hydrogen gas. This process dilutes some of the emissions reductions benefits of FCVs, but generally makes FCVs attractive relative to ICE vehicles: UCS found that the Hyundai Tucson FCV on hydrogen from natural gas reduced GHG emissions per mile by 34% compared to its gasoline-powered counterpart.[67] Hydrogen is increasingly being produced by electrolysis, which uses electricity to split water into hydrogen and oxygen; in California, that electricity is produced with increasingly cleaner generating resources, and state law requires that at least 33 percent of hydrogen produced at state-supported hydrogen stations must be produced with low-carbon resources.[68] Under this production method, the Hyundai Tucson FCV would produce 54% less GHG emissions than its ICE counterpart.[69] Renewable liquid reforming and fermentation are other production methods that use biomass to produce hydrogen and may provide emissions reductions benefits relative to gas reforming methods.[70]

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[61] https://cafcp.org/sites/default/files/FCEV-Sales-Tracking.pdf
[62] https://afdc.energy.gov/stations/#/find/nearest
[63] https://www.energy.ca.gov/2017publications/CEC-600-2017-011/CEC-600-2017-011.pdf
[64] https://cleanvehiclerebate.org/eng/eligible-vehicles
[65] https://afdc.energy.gov/stations/#/find/nearest
[66] *Id.*
[67] https://www.ucsusa.org/sites/default/files/attach/2014/10/How-Clean-Are-Hydrogen-Fuel-Cells-Fact-Sheet.pdf
[68] *Id.*
[69] *Id.*
[70] https://afdc.energy.gov/fuels/hydrogen_production.html

Because of FCVs' zero emission attributes and a focus on increasingly cleaner forms of hydrogen production, FCVs are also expected to play a role in achieving California's GHG emission reduction targets. A CEC analysis finds that in a pathway to achieving 80% GHG reductions by 2050 from 1990 levels, FCVs may comprise as much as 10% of light-duty sales in 2030.[71]

Vehicle Costs

FCVs are significantly more expensive than ICE vehicles on an upfront basis. The Toyota Mirai, comparable to a Toyota Prius in size and appearance, has a MSRP of $58,500. The Hyundai Nexo, comparable to the Hyundai Kona, has a MSRP of $58,300. Leasing options may provide a monthly payment that is costly yet more comparable to ICE vehicle leases. Automakers generally include 3 years of complementary fuel up to $13,000-$15,000 in their leases.

According to the California Fuel Cell Partnership, hydrogen prices range from $12.85 to upwards of $16 per kilogram (kg).[72] At $14 per kg, the price per energy equivalent to gasoline translates to $5.60 per gallon. NREL estimates that fuel prices could drop to $8-$10 per kg within the 2020-2025 period, at which point FCVs would approach fuel cost parity with ICE vehicles, but it may still be more costly depending on gasoline prices.[73]

Infrastructure Costs

Hydrogen fueling infrastructure cost is perhaps the most significant barrier to the development of the light-duty FCV market. The CEC estimates that the total cost of reaching its 100 station goal will approach $201.6 million, or over $2 million per station.[74] All-in costs, including installation and overhead, are around $2.5 million for 180 kg/day stations, and up to $4 million for 360 kg/day stations. CEC provided the majority of funding to support station deployment costs, with some matching funds secured from other agencies and private sector stakeholders.[75] As the DOE notes, it is difficult to develop a comprehensive infrastructure network for distribution of hydrogen to hundreds or thousands of fueling stations.[76] Producing hydrogen on site may reduce distribution costs, but raises production costs if on-site production facilities are not already available. In short, the hydrogen station market has relied on government support to grow, and the CEC identifies a strong need for private investment to achieve economies of scale and reduce costs in a manner that ultimately supports the self-sufficiency of the technology.

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[71] https://www.ethree.com/wp-content/uploads/2018/06/Deep_Decarbonization_in_a_High_Renewables_Future_CEC-500-2018-012-1.pdf
[72] https://cafcp.org/content/cost-refill
[73] *Id.*
[74] https://www.energy.ca.gov/2017publications/CEC-600-2017-011/CEC-600-2017-011.pdf
[75] *Id.*
[76] https://afdc.energy.gov/fuels/hydrogen_production.html

3 Assessment of Technology and Fuel Options – Medium and Heavy Duty Vehicles

This section describes clean vehicle technology and fuel options for medium- and heavy-duty vehicles. Medium-duty is defined as Class 3 to Class 6 vehicles, or those with a gross vehicle weight rating (GVWR) of 10,000 lbs to 26,000 lbs. Heavy-duty vehicles are Class 7 and 8, with a GVRW greater than 26,000 lbs. Similar to Section 2, the options are organized into two sub-sections: vehicle efficiency improvements (using conventional fuels) and clean fuels. Each option is discussed in terms of technology readiness, emissions impacts, vehicle costs, and infrastructure costs.

3.1 Vehicle Efficiency Improvements

Expand Fuel Economy Regulations

Technology Readiness

One strategy to reduce emissions from medium- and heavy-duty vehicles involves fuel economy improvements for diesel vehicles, which make up the overwhelming majority of the medium- and heavy-duty fleet today. Fuel economy and GHG standards have applied to light-duty vehicles since the 1970s, but they are relatively new for heavier vehicles: Phase 1 standards were finalized by U.S. EPA and the National Highway Traffic Safety Authority (NHTSA) in 2011 and applied to model years 2014-2018.[77] Phase 2 standards were finalized in 2016 and apply to model years 2019-2027.[78] Although medium- and heavy-duty vehicles comprise only 7% of the vehicles on the road, they consume roughly a quarter of the fuel used for on-road transportation; for that reason, targeted fuel economy and GHG standards can yield significant fuel savings and emissions reductions.[79] The implementation of the federal medium- and heavy-duty vehicle fuel economy and GHG standards is uncertain at this time. Portions of the regulation have been delayed and are currently subject to litigation.

There is a suite of readily-available technological improvements that fleet operators can take advantage of to improve the efficiency of their vehicles and reduce fuel costs – particularly for heavy-duty long-haul combination vehicles. Additional tractor and trailer equipment can be installed to improve aerodynamics and fuel economy between 2-7%.[80] Long-haul combination trucks can also take advantage of low rolling resistance and wide-base single tires, which can also improve fuel economy 2-5%; applications for Class 3-6 vehicles are limited. Tire pressure devices can monitor and even adjust pressure to reduce energy losses from tire underinflation and decrease tire maintenance costs. Idle reduction technologies such as fuel operated heaters/coolers, auxiliary power units, and auto start/stop systems, and vehicle electrification for in-truck appliances can reduce reliance on the main engine for heating and cooling; these technologies can reduce idling time by 50% and are for the most part

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[77] https://www.ucsusa.org/sites/default/files/legacy/assets/documents/clean_vehicles/HDV-emissions-fuel-economy-factsheet.pdf
[78] https://www.arb.ca.gov/msprog/onroad/caphase2ghg/caphase2ghg.htm
[79] *Id.*
[80] http://www.trb.org/Publications/Blurbs/176904.aspx

applicable to all medium- and heavy-duty vehicles.[81] Engine governors can set limits on highway vehicle speeds, and as a general rule, each 1 mph reduction over 55 mph can improve fuel economy by 0.1 MPG. Trucks that travel at highway speeds often are mostly to benefit, and most fleet operators have governors set to 68 mph or lower. Truck refrigeration units (TRUs), which are typically powered by diesel independent of the trucks engine, can benefit from increased efficiency of hybrid electric technologies that allow for TRUs to be plugged in when stationary. These technologies can reduce TRU diesel consumption by 16%. Finally, similar to idle reduction, truck stop electrification (TSE) can improve vehicle efficiency by using external electric power to provide heating, cooling, and other services; TSE can reduce energy use by 74% compared to idling a truck engine. However, trucks may need additional internal wiring installed to support TSE.

Emissions Impacts

The emissions impacts of individual measures to improve fuel economy of trucks and fleets will depend on a number of factors, including duty cycle, vehicle (weight) loads, and driving conditions. Idle reduction technologies such as auxiliary power units can reduce NOx, particulate matter, and carbon dioxide emissions by 12%, 11%, and 3% respectively.[82] TSE can dramatically reduce these same pollutants by 98%, 93%, and 80% respectively relative to an idling diesel engine.

If implemented as adopted, the overall impact of fuel economy and GHG standards on national trucking emissions will be significant. Phase 1 standards were estimated to reduce GHG emissions by 270 million metric tons – equivalent to the lifetime emissions of 4 million light-duty cars and trucks.[83] Phase 2 standards are estimated reduce GHG emissions by approximately 1 billion metric tons over the life of the vehicles regulated by the standards.[84] The Union of Concerned Scientists found that while Phase 2 standards are expected to reduce fuel consumption by 36% in 2027 from 2010 levels, 40% reductions are achievable by 2025 with technology that is already being deployed or piloted; this improvement would reduce GHG emissions by an additional 40 million metric tons annually.[85] Unfortunately, there is currently no reliable information to depict how these standards have affected fuel consumption and GHG emissions to date.

Overall, standards are critical tools for reducing transportation sector emissions while saving fleet operators billions in fuel costs and providing regulatory certainty for manufacturers. However, emissions reductions from improved medium- and heavy-duty fuel economy for diesel vehicles are being offset by increases in vehicle miles traveled in the trucking industry. Demand for diesel fuel increased by 3.1% in 2018, likely in response to e-commerce and broader economic trends.[86] In sum, fuel economy and GHG standards are an important pathway for reducing emissions from medium- and heavy-duty vehicles, but these emissions reductions are not immune to increased demand for trucking so long as diesel vehicles comprise the bulk of the truck fleet.

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[81] The American Trucking Association estimates that long-haul truckers idle for an average of six hours per day.
[82] http://www.trb.org/Publications/Blurbs/176904.aspx
[83] https://www.govinfo.gov/content/pkg/FR-2016-10-25/pdf/2016-21203.pdf
[84] *Id.*
[85] https://www.ucsusa.org/sites/default/files/attach/2015/07/proposed-heavy-duty-vehicles-standards.pdf
[86] https://rhg.com/research/preliminary-us-emissions-estimates-for-2018/

Vehicle Costs

Costs to retrofit or install efficient equipment to diesel trucks are relatively inexpensive but can yield significant fuel cost savings. Aerodynamic improvements can cost between $300-$3,100 per device.[87] Low rolling resistance tires cost up to $50 per tire and wide-base tires save $130 on average when trucks are equipped with them. Tire pressure monitoring systems cost approximately $750 while automatic tire inflation systems cost $1,000 before installation and maintenance. Fuel-operated heaters typically cost $800-$1,500, auto start/stop systems can cost between $1,500-$2,500, and auxiliary power units may cost $8,000-$12,000 before installation and maintenance. Engine governor costs are marginal. Hybrid electric TRUs cost roughly 10% more than a comparable diesel model. TSE may require additional wiring and equipment that costs roughly $3,000.

Most of the nation’s large trucking companies, and many smaller companies, invest in at least some of these fuel saving technologies. Fueling costs are typically the second largest component of truck operating cost (after driver wages), so there is a strong incentive for motor carriers to adopt fuel saving technologies that are cost effective. EPA’s SmartWay program helps to encourage these technologies by providing information about effectiveness, providing tools for fuel use benchmarking, and rewarding those who voluntarily adopt fuel saving measures by allowing use of SmartWay branding. However, a large portion of heavy-duty trucks are owned by independent owner-operators or small fleets; these entities may lack the resources to invest in fuel saving technologies or may lack knowledge of the benefits.

Infrastructure Costs

Most efficiency improvements do not require the installation of infrastructure, except for TSE. Adding electrical capacity to truck parking spots may add $1,700-$2,500 per space. Some TSE operators provide heating and cooling through ventilators that connect to the side of the long-haul truck tractor and charge a time-based fee for service. These systems may cost $5,000-$10,000 per space.

3.2 Clean Fuels

Biodiesel

Technology Readiness

Biodiesel is produced via the processing of virgin oils (e.g., soy or canola), byproducts of other processes (e.g., corn oil extracted via corn ethanol production), and waste products (e.g., used cooking oil). Biodiesel can be blended up to 5% with no labeling required at the pump; however, anything above 20% requires special labeling at retail fuel pumps. Most new medium- and heavy-duty engines on the road today have warranties that accommodate up to 20% blend of biodiesel with conventional diesel.

Statewide, biodiesel accounts for approximately 6% of diesel fuel sold, based on data reported for the Low Carbon Fuel Standard. However, biodiesel use has been discouraged in the South Coast Air Basin due to concerns about potential increased NOx emissions, as discussed below.

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[87] http://www.trb.org/Publications/Blurbs/176904.aspx

Emissions Impacts

Depending on feedstock, B20 can reduce GHG emissions by 10%-18%. B20 reduces emissions of volatile organic compounds (VOCs) by about 18% and reduces PM by an average of 17% in heavy duty engine model years 2006 and older. Biodiesel has been found to slightly increase NOx emissions, at least in some instances. The impact is uncertain and appears to vary depending on the biodiesel feedstock (soy vs. animal fats) and the engine age. Researchers at UC Riverside tested model year 2006 and 1991 truck engines running on B5 and B10 blends of both soy and animal-based biodiesel. The tests found statistically significant increases in NOx emissions of 0.7% to 3.6% in some cases, although other cases did not show statistically significant differences in NOx emissions due to B5 and B10.

Vehicle Costs

B20 can be used in conventional diesel vehicles, and in California, B20 is competitively priced with conventional diesel. Vehicles using biodiesel may have minor increased maintenance costs, since biodiesel can loosen accumulated deposits in fuel injectors and fuel lines, which may clog the fuel filter. As a result, users may need to replace the fuel filters after the first couple of tanks of biodiesel. While not necessarily maintenance related, biodiesel gels at cooler temperatures, which prevents the fuel from passing through fuel lines and injectors. B20 has a gel point of -15° F, so fleet managers using biodiesel need to monitor the fuel in colder temperatures and adjust blend levels based on the season.

Infrastructure Costs

Biodiesel fueling can often use existing diesel fueling equipment, so biodiesel fueling infrastructure is relatively inexpensive. All existing tanks and associated underground equipment (e.g., tanks and pipes) are compatible with B20, and most are compatible with biodiesel blends up to B100. However, existing equipment must be cleaned prior to using a new fuel, which typically costs under $2,000. Due to concerns about NOx emissions increases as noted above, biodiesel use has been discouraged in the South Coast Air Basin, since ozone formation in the region is primarily driven by NOx. There is currently only one retail fueling station selling biodiesel in the County – a 76 station in Ontario. Biodiesel is more commonly used in northern California and the rest of the country.

Renewable Diesel

Technology Readiness

Renewable diesel is a liquid fuel produced from biomass. It meets the fuel specification requirements of ASTM D975 for petroleum diesel fuel, meaning that although it is produced from biomass, it has the properties of conventional diesel. Renewable diesel is produced from the same biomass used to make biodiesel via different processes.

Renewable diesel is a drop-in replacement and can be blended into the conventional diesel supply without limitations. There are labeling requirements when the fuel is blended above 5%, and there are multiple retailers that have started to sell renewable diesel at higher level blends. Due in part to incentives that result from the Low Carbon Fuel Standard, use of renewable diesel has been increasingly rapidly in California. In 2019, renewable diesel accounted for approximately 16% of all diesel sold in the state, based on reporting for the Low Carbon Fuel Standard. This is up from approximately 4% in 2015.

Most of this renewable diesel is blended with conventional diesel and thus largely unknown to truck owner and operators.

Emissions Impacts

Lifecyle emissions of renewable diesel depends on the fuel feedstock, but renewable diesel offers similar GHG emissions reductions to biodiesel. RD5 reduces GHG emissions by about 3% and RD100 reduces GHG by about 66%. Renewable diesel also reduces criteria pollutant emissions, and can provide PM2.5 reductions of up to 35%.

Vehicle Costs

Because renewable diesel is a drop-in fuel, it can be used in existing diesel vehicles and does not have any incremental cost. Renewable diesel is priced competitively with conventional diesel, and does not have any additional operations and maintenance costs as compared to conventional diesel.

Infrastructure Costs

Because renewable diesel is blended into conventional diesel, it does not need separate fueling infrastructure. As noted above, diesel sold in California currently contains approximately 16% renewable diesel on average.

Natural Gas

Technology Readiness

Natural gas is a fossil fuel primarily used in transit buses, refuse hauling, and over-the-road trucks. Natural gas is consumed either as compressed natural gas (CNG) or liquefied natural gas (LNG). About 200 million gasoline gallon equivalents of natural gas are consumed in California annually, with most of that currently being via CNG (77%).

There is modest natural gas vehicle (NGV) commercial availability in medium-duty vehicles. In Class 4-5 vocations, NGVs are well suited for shuttles and urban delivery trucks, and in Class 6 vocations they are used in regional haul applications. There are some natural gas engines available in the Class 4-5 segment that are available at scale, but there is limitation to NGVs in this segment because the compressed storage tanks of CNG require special consideration in the design of the chassis. For example, the CNG fuel tank may need to be placed in such a way that reduces cargo space for delivery vans, which makes an NGV a less appealing alternative to a conventionally fueled vehicle.

Natural gas has more potential in heavy-duty vehicles, and there is good availability of NGVs in vocations like drayage, regional haul, refuse, and transit. According to the Port of Los Angeles and Port of Long Beach’s *2018 Feasibility Assessment for Drayage Trucks*, NGVs comprise 3% of the Ports’ drayage fleet and are the most dominant alternative fuel vehicle drayage truck platform with demonstrable model availability from major original equipment manufacturers (OEMs), dealership engagement, production capabilities, and customer interest.[88] Unlike medium-duty vehicles, the heavy-duty truck manufacturing industry is rarely vertically integrated, and the tractor, engine, powertrain, and trailer are typically manufactured separately. For heavy-duty vehicles (class 7 and 8), there is only one certified CNG engine in California (Cummins Westport's CWI line which includes a 6.7 liter engine, a 9 liter engine, and a 12 liter engine). These engines cover a wide array of performance requirements, and are good options for transit buses and refuse truck fleets. Natural gas is particularly popular in refuse trucks, and all of the major bus manufacturers have a CNG option.

Emissions Impacts

Natural gas offers modest emissions benefits over diesel, with a roughly 12% GHG emission reduction on a lifecycle basis.

Natural gas also offers NOx and PM2.5 benefits over diesel. NGVs can reduce PM2.5 up to 70%, as compared to diesel vehicles, and NGVs reduce NOx by 50-90%. NOx reductions vary based on the NGV engine technology; new low-NOx engines meet a voluntary emissions standard that is 90% below the current NOx standard.

Vehicle Costs

Class 4-6 NGVs have an incremental cost of between $25,000 to $50,000, as compared to diesel vehicles. This is a 50% to 80% price increment over the cost of a convention Class 4-6 diesel truck ($48,000 to $63,000). Class 7-8 have an incremental cost of $40,000 to $60,000 over conventional diesel vehicles. This is a 37% price increment over the cost of a conventional Class 7-8 diesel truck ($110,000 to $160,000). Total cost of ownership of the vehicle, which includes fuel costs, can be slightly less for certain vocations of NGV, particularly as vehicle miles traveled increases. Vehicle costs can also be defrayed by incentives; the HVIP program, for instance, provides vehicle incentives, and the RFS and LCFS programs both provide incentives that are typically passed on to the fleet or end user in some way.

Infrastructure Costs

The costs for natural gas fueling infrastructure varies by the size of the fueling station. Assuming medium-duty fleet vehicles return to a base, they can be fueled at a centralized location using a fast fill or time fill station. Fast fill stations are best suited for retail situations and use a compressor on site to compress the gas to a high pressure and store the gas in storage vessels so it is available for quick fueling. Fast fill stations mimic the experience of a traditional gasoline fueling station and allow drivers to fill a 20 gallon tank in less than 5 minutes. Time fill stations are used by fleets and fill vehicles with gas directly from the compressor. Depending on the number of vehicles to be fueled and the compressor size, time-fill stations can take between a few minutes to several hours to fuel vehicles. The table below summarizes these costs. As shown below, time fill stations are generally less expensive to deploy and operate than fast fill stations due to smaller compressors and lower energy consumption.[89]

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[88] Couch et al., *2018 Feasibility Assessment for Drayage Trucks*, prepared for The Port of Los Angeles and Port of Long Beach, April 2019, available at: http://www.cleanairactionplan.org/documents/final-drayage-truck-feasibility-assessment.pdf/

[89] *Id.*

Table 1: Natural Gas Fueling Infrastructure Costs

Size	Type	Serving	Total Cost
Small Station **85-170 DGE/day**	Fast Fill	10-15 work trucks	$400-600k
	Time Fill	10-15 work trucks	$250-500k
Medium Station **425-680 DGE/day**	Fast Fill	50-80 shuttles/vans	$700-900k
	Time Fill	25-40 trucks	$550-$850k
Large Station **1,275-1,700 DGE/day**	Fast fill, retail	Refuse trucks, tractors, etc.	$1.2-$2.0 million

Renewable Natural Gas

Technology Readiness

Renewable natural gas (RNG) is derived from biomass or other renewable resources, and is a pipeline-quality gas that is fully interchangeable with conventional natural gas. RNG can be produced from a variety of feedstocks by three methods: anaerobic digestion, thermal gasification, and power to grid technology. Most RNG that is currently dispensed in California is derived from landfills.

Renewable natural gas is a drop-in fuel that can be used in NGVs. About 67% of California's natural gas consumption in 2017 was RNG, and RNG accounted for more than 60% of California's market for natural gas as a transportation fuel. This percentage will increase as major natural gas consumers (e.g., Los Angeles County Metropolitan Transportation Authority) expand their RNG demand significantly.

For more information about the availability of NGVs, see the Natural Gas section above.

Emissions Impacts

RNG reduces GHG emissions about 54%-92%, depending on the feedstock. Most RNG in California is made from landfill gas, which reduces GHG emissions by 56%. Production will likely shift over time to lower carbon intensity RNG made from feedstocks such as the anaerobic digestion of animal manure and digesters deployed at waste water treatment plants.

RNG provides similar tailpipe emissions reductions to conventional natural gas, with PM2.5 reductions of 70% and NOx reductions between 50% and 90%, depending on engine technology.

Vehicle Costs

RNG is used in NGVs. Class 4-6 NGVs have an incremental cost of between $25,000 to $50,000, as compared to diesel vehicles. Class 7-8 have an incremental cost of $40,000 to $60,000 over conventional diesel vehicles. Because of lower fuel costs than diesel (and similar costs to conventional natural gas), total cost of ownership of the vehicle can be slightly less for certain vocations of NGV, particularly as vehicle miles traveled increases.

Infrastructure Costs

Because RNG is a drop-in fuel, it can use existing conventional natural gas fueling infrastructure. For more information about natural gas fueling infrastructure costs, see Table 1.

Plug-In Electric Vehicles

Technology Readiness

EV battery technology continues to advance at a rapid pace, providing new opportunities for the electrification of a broad suite of medium- and heavy-duty fleets. Nearly 80 zero-emission electric medium- and heavy-duty vehicle models are currently eligible for CARB's Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP).[90] However, given the diversity in the specifications, duty cycles, and ultimate function of these vehicles, there exists some diversity in the commercialization status of different medium- and heavy-duty vehicle types. In general, transit buses and vehicles that travel short distances on a day-to-day basis are ripe for transportation electrification. Vehicles that travel greater distances (i.e. long-haul semi-truck) are still in development, but a growing number of manufacturers and customers are driving greater investment in longer-range EV deployments.

Transit Buses

Transit buses are the most widely deployed heavy-duty EV. California's public transit agencies have already deployed over 150 zero-emissions buses – the overwhelming majority of which are all-electric – and based on bus orders and planned purchases, CARB expects that figure to rise to 1,000 by 2020.[91] Transit bus electrification is also buoyed by CARB's Innovative Clean Transit regulation, which establishes a statewide goal for the state's transit agencies to transition to 100 percent zero-emission bus fleets by 2040.[92] There are currently 27 zero-emission electric transit bus models eligible for HVIP incentives with battery packs ranging from 94 kWh to 660 kWh.

Transit buses are well-suited to electrification for several reasons. They experience longer idle times than other medium- and heavy-duty vehicles, where diesel vehicles would typically waste more fuel.[93] Transit buses also run predictable routes in a defined geographic area, allowing fleet operators to more easily assess how buses may perform under routine conditions. Fleets are also typically housed in centralized depots where charging infrastructure can be accessed and managed. In addition, transit buses usually operate in urban areas where vehicle emissions and related human health concerns are greatest.

The National Renewable Energy Laboratory (NREL) gave Proterra's battery electric buses a "Technology Readiness Level" of seven out of nine in 2017, indicating an ability for the buses to perform their essential functions and potential to scale commercially.[94] In terms of reliability, transit bus battery packs

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[90] https://www.californiahvip.org/eligible-technologies/#your-clean-vehicles
[91] https://ww2.arb.ca.gov/news/california-transitioning-all-electric-public-bus-fleet-2040
[92] *Id.* The Innovative Clean Transit regulation does not specify that transit bus be electric, although it is expected that electric buses will play a large role in meeting the zero-emission requirements of the regulation.
[93] http://www.caletc.com/wp-content/uploads/2019/01/Literature-Review_Final_December_2018.pdf
[94] https://www.nrel.gov/docs/fy17osti/67698.pdf

are expected to last throughout the useful life of the vehicle. BYD 40’ and 60’ model battery packs are intended to last 20 to 25 years, which includes a 12 year warranty for the life of the bus as well as second-life energy storage applications.[95]

Shuttle and School Buses

Shuttle buses are similar to transit buses in that they travel short distances on fixed routes and may be subjected to longer idle times that other vehicles. CARB also expects shuttle bus electrification to increase substantially over the next decade.[96] There are currently seven electric, zero-emission shuttle bus models eligible for HVIP incentives with battery packs ranging from 52 kWh to 106 kWh.

School buses also generally fit the ideal electrification profile, running short, predictable routes in regular morning and afternoon cycles. They remain stationary most of the day, providing ample time for recharging and opportunity to provide valuable grid services. However, there are challenges to scaling school bus electrification, including rigorous safety standards for all school bus technologies, lack of available models in the market, upfront costs, and slowness of legacy school bus manufacturers to develop electric bus models – although Thomas Built now has a commercially available school bus.[97] There are eleven school bus models eligible for HVIP incentives, with battery packs ranging from 88 kWh to 220 kWh.

Class 4-6 Vehicles

Electrification has not significantly transformed medium-duty electrification to date, and it is estimated that there are about 300 medium-duty EVs in the United States.[98] However, given their short daily ranges and last-mile applications, local delivery and utility vehicles are prime candidates for electrification and they are beginning to experience greater deployment. Companies such as Frito Lay, Staples, Coca-Cola, Goodwill, FedEx, and UPS are beginning to incorporate medium-duty EVs into their fleets.[99] FedEx recently announced that it would purchase 100 V8100 electric delivery vehicles from Chanje, and lease 900 from Ryder.[100] UPS recently announced advances in charging station management would enable it to electrify all of its 170 delivery trucks operating in London.[101] Moreover, the California Hybrid, Efficiency, and Advanced Truck Research Center predicts that medium-duty delivery EVs will reach a widespread commercialization phase starting in 2020.[102] Currently, six electric delivery truck and panel van models are eligible for HVIP incentives, with battery packs ranging from 96 kWh to 128 kWh.

Class 7-8 Vehicles

Electrification of heavy-duty vehicles is still limited, although long-haul vehicles are beginning to enter the demonstration phase. Drayage and refuse trucks are somewhat more mature and have travel

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[95] http://www.caletc.com/wp-content/uploads/2019/01/Literature-Review_Final_December_2018.pdf

[96] *Id.*

[97] *Id.*

[98] *Id.*

[99] *Id.*

[100] https://about.van.fedex.com/newsroom/fedex-acquires-1000-chanje-electric-vehicles/

[101] https://pressroom.ups.com/pressroom/ContentDetailsViewer.page?ConceptType=PressReleases&id=1521473412769-768

[102] http://www.caletc.com/wp-content/uploads/2019/01/Literature-Review_Final_December_2018.pdf

requirements that create advantages for electrification, though few models exist in the market today. Over 40 all-electric drayage trucks have been deployed in California and have helped reduce emissions from port operations.[103] Long-haul semi-trucks currently face clear challenges to electrification due to limited electric range relative to their diesel counterparts.[104] Energy density and weight of large battery packs are partially responsible for this challenge. However, the semi-truck space is evolving and several major manufacturers and suppliers, including Tesla, BYD, TransPower, Daimler/Freightliner, Volvo, Cummins, and others have either deployed or planning to deploy electric trucks or battery packs soon. The much-anticipated 300-500 mile Tesla Semi is expected to begin production in 2020 and Tesla plans to scale production to support production of 100,000 trucks per year.[105] Daimler's Freightliner intends to begin production of its 250-mile eCascadia model by 2021 and has already delivered its first medium-duty electric delivery model.[106] Navistar also announced its intent to develop and sell electric Class 8 truck models by 2025. As of 2018, two OEMs offered a total of 2 electric drayage truck (day cab) models and 12 models are expected to be available by 2021.[107] Moreover, 65 electric drayage trucks are currently or will soon be undergoing testing at the Ports of Los Angeles and Long Beach – including many models from the OEMs identified in this section.[108]

In short, increased energy density in batteries is needed to reduce overall vehicle weight and increase electric range. The most common battery chemistry used in EVs today is lithium-ion, and there are several variations of lithium-ion chemistries to consider in medium- and heavy-duty applications.[109] However, different chemistries often create trade-offs between vehicle range and life span of the battery (charge cycles): for example, lithium manganese oxide batteries have relatively high energy density (Wh/kg) but relatively low lifespan (1500+ cycles).[110] More research is being conducted to continue the development of lighter, more efficient batteries for use in medium- and heavy-duty applications.

Overall, medium- and heavy-duty EVs are a quickly maturing alternative fuel vehicle type with significant opportunity for growth in California, although challenges remain. EVs are energy efficient and zero-emission, battery costs are continuing to decline, fuel costs can be very competitive with alternatives, and the ubiquity of the electric grid makes access to electricity straightforward in most cases. However, vehicle range, refueling time, and if left unmanaged, electricity costs, can prove to be challenging for medium- and heavy-duty EVs in certain applications in the near-term – particularly in the long-haul heavy-duty segment.[111]

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[103] *Id.*

[104] *Id.*

[105] https://electrek.co/2019/04/25/tesla-semi-delay-electric-truck-production-next-year/

[106] https://www.trucks.com/2018/06/06/daimler-unveils-electric-freightliner-cascadia/

[107] Couch et al., *2018 Feasibility Assessment for Drayage Trucks*, prepared for The Port of Los Angeles and Port of Long Beach, April 2019, available at: http://www.cleanairactionplan.org/documents/final-drayage-truck-feasibility-assessment.pdf/

[108] *Id.*

[109] http://www.caletc.com/wp-content/uploads/2019/01/Literature-Review_Final_December_2018.pdf

[110] *Id.*

[111] Couch et al., *2018 Feasibility Assessment for Drayage Trucks*, prepared for The Port of Los Angeles and Port of Long Beach, April 2019, available at: http://www.cleanairactionplan.org/documents/final-drayage-truck-feasibility-assessment.pdf/

Emissions Impacts

EVs produce zero tailpipe emissions, potentially alleviating local emissions impacts from mobile sources relative to other vehicles. Well-to-wheels emissions are dependent on the regional electric generation mix. California's grid is one of the cleanest in the nation: 29 percent of California's power mix came from renewable generation in 2017 – not including large hydro.[112] Moreover, Governor Brown signed Senate Bill 100 in 2018, which ramps up the state's Renewable Portfolio Standard requirements to 60% by 2030 and 100% by 2045.[113] Therefore, as the state and regional electricity systems get cleaner, medium- and heavy-duty EV well-to-wheels emissions will continue to decline.

Even with California's current grid mix, EVs are a competitive option for reducing vehicle emissions. An analysis by the NRDC and California Clean Freight Coalition found that short haul delivery truck electrification (less than 80 miles per day) in areas of the country with relatively low-carbon electric generation portfolios would reduce particulate matter, NOx, and GHG emissions up to 90% per mile relative to conventional diesel vehicles.[114] Union of Concerned Scientists (UCS) and the Greenlining Institute estimated that an electric transit bus on California's current grid mix would produce approximately 74 percent less GHG emissions per mile relative to a conventional diesel bus.[115] Moreover, CARB found that even if an electric transit bus ran on electricity generated completely from natural gas travelled twice as far as comparable compressed natural gas (CNG) bus.[116] This is primarily due to the superior efficiency of EVs: NREL's Foothill Transit demonstration study found that Proterra buses achieved a MPGe of 17.35, whereas the typical fuel economy of a transit bus is 3.26 MPG.[117] EVs are also a key part of reducing transportation sector emissions consistent with reaching California climate goals of reducing economy-wide emissions 80 percent by 2050 from 1990 levels: in its analysis, the California Energy Commission finds that EVs will be the dominant medium-duty alternative fuel vehicle (~60% of sales) and that EVs will play a non-trivial role in decarbonizing heavy-duty fleets (~20% of sales) by 2050.[118] However, sales for both vehicle classes will need to increase rapidly over the next decade to reach the growth figures estimated in the report.

Vehicle Costs

At a high level, upfront costs for medium- and heavy-duty EVs generally exceed those of comparable fossil fuel vehicles. However, increasing economies of scale and battery technology improvements are continuing to lower the total upfront cost of EVs.

Based on recent literature, ICF estimates the average upfront cost of a new electric transit bus is $820,000, while the average cost of a new, comparable diesel bus is around $435,000.[119] However, it's important note that costs have declined substantially in a relatively short period of time: for example,

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[112] https://www.energy.ca.gov/almanac/electricity_data/total_system_power.html
[113] https://www.energy.ca.gov/renewables/
[114] https://www.nrdc.org/file/3432/download?token=T-gD6FNl
[115] https://www.ucsusa.org/sites/default/files/attach/2016/10/UCS-Electric-Buses-Report.pdf
[116] http://www.caletc.com/wp-content/uploads/2019/01/Literature-Review_Final_December_2018.pdf
[117] https://www.nrel.gov/docs/fy17osti/67698.pdf; https://afdc.energy.gov/data/10310
[118] https://www.ethree.com/wp-content/uploads/2018/06/Deep_Decarbonization_in_a_High_Renewables_Future_CEC-500-2018-012-1.pdf
[119] http://www.caletc.com/wp-content/uploads/2019/01/Literature-Review_Final_December_2018.pdf

40’ Proterra buses were introduced in 2010 at $1.2 million, decreasing to $900,000 several years later and approximately $750,000 today.[120]

Electric medium-duty vans and trucks were estimated to cost approximately $130,000-$170,000 whereas the conventional diesel vehicle costs approximately $80,000 in 2015.[121] However, the specific cost differentials will depend on the vocation and model of the vehicle. Estimates for heavy-duty trucks are more speculative given the current limited availability of electric models. ICF estimates that Class 6-8 short-haul electric trucks are priced around $200,000-$300,000 relative to $145,000 for a comparable diesel truck; given that many electric trucks in the U.S. are imported from China, the electric truck prices include estimated tariffs levied on the import of these vehicles.[122] Electric drayage trucks were estimated to cost $208,000 relative to $108,000 conventional drayage trucks in 2020.[123] Thor and Tesla estimate their long-haul Class 8 semi-trucks will cost approximately $150,000-$250,000 depending on model’s range, compared to $125,000 for a diesel equivalent.[124]

Although upfront cost is an important factor in vehicle fleet purchase decisions, total cost of ownership (TCO) is generally paramount. TCO is dependent on a number of factors that may vary by geography and specific fleet operational conditions, including fuel costs, maintenance costs, charging infrastructure costs, access to incentives, duty cycles, and regulations, among other elements. As a general principle, it is acknowledged that EVs are cheaper to maintain than conventional vehicles due greater reliability of batteries and electric motors as well as fewer fluids and moving parts. CARB estimates TCO savings of $150,000-$250,000 per electric bus relative to diesel.[125] Estimates for heavy-duty trucks are less competitive: National Center for Sustainable Transportation estimates that the total cost of ownership of an electric truck in 2030 is estimated at approximately $430,000, compared to $250,000 for a diesel truck.[126] However, the International Council on Clean Transportation estimates that electric trucks with overhead catenary charging are expected to cost 25%-30% less on a TCO basis than diesel vehicles in 2030.[127]

Infrastructure Costs

Accessible charging infrastructure is critical to the operation of medium- and heavy-duty EVs, and lack of charging infrastructure is currently a barrier to all classes of EVs. Although the industry is converging on standards for conductive (i.e. plug-based) charging such as J3068 for alternating current (AC) charging

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[120] *Id.*

[121] *Id.*

[122] The tariffs are estimated to add 20% to the overall price of the vehicle. ICF Resources, LLC, *Economic Impacts of the Accelerated Deployment of Zero- and Near-Zero NOx Emissions Technologies in the Heavy-Duty Vehicle Sector Task 2: Implementation Scenarios Technical Memorandum*, May, 1, 2019

[123] *Id.*

[124] *Id.*

[125] *Id.*

[126] Miller, M. Q. Wang, and L. Fulton, Truck Choice Modeling: Understanding California's Transition to Zero-Emission Vehicle Trucks Taking into Account Truck Technologies, Costs, and Fleet Decision Behavior, University of California at Davis and the National Center for Sustainable Transportation, 2017.

[127] http://www.caletc.com/wp-content/uploads/2019/01/Literature-Review_Final_December_2018.pdf

and J3105 for overhead catenary charging, infrastructure cost and optimization may prove to be a challenge for fleet operators considering EVs.

Infrastructure cost can be broken out into three primary categories: charging station costs, maintenance costs, and “make-ready” costs, which include all costs related to upgrading electrical equipment upstream of the station to support EV charging. Although some medium- and heavy-duty EVs may utilize Level 2 charging equipment, which is relatively inexpensive and charges at a slower rate (~6.6 kW), the battery capacities and duty cycles of these vehicles may require much faster charging in depot charging configurations. Direct Current (DC) Fast Charging stations that charge EVs at 50 kW may cost approximately $50,000 per station, which would be able to charge a 400 kWh bus battery overnight.[128] 450 kW charging may cost roughly $350,000 per station.[129] Beyond, depot charging, fast on-route charging may be available for EVs that travel in fixed, predictable routes (e.g. transit buses) and may cost around $300,000-$350,000 per station.[130] Vehicle-duty cycles will likely govern decision-making on charging infrastructure investments – particularly for heavy-duty drayage trucks: single shift trucks with 10-14 hours of downtime daily may only need up to 50 kW of charging capacity, but double shift trucks may require upwards of 150 kW on average to complete daily routes.[131] Inductive charging provides opportunities for refueling without the use of a plug, but are typically more expensive and less commercially available than conductive charging: a 250 kW WAVE wireless charger costs $286,000, and in-road and catenary charging may cost $1.3 million to $6 million per mile.[132] These route-based charging configurations may allow for EVs with smaller batteries to complete duty cycles of longer-range EVs and may be appropriate for short-distance, high-frequency travel corridors.[133] Maintenance costs may reach up to $18,000 per year per station for fast on-road charging applications, but are typically much lower for depot and slower charging stations.[134] Make-ready costs also vary widely and are dependent on the capacity of the charging equipment installed, distance from electrical panels, labor costs, and more: make-ready costs for a depot DC Fast Charging station may range from $20,000-$70,000 while installation of the 250 kW WAVE wireless charger may exceed $200,000.

Fuel Cell Vehicles

Technology Readiness

Hydrogen fuel cell technology development began at the federal level in the 1970s[135], but despite recent efforts to bring the technology to market, commercial deployment has been relatively limited to date. Similar to medium- and heavy-duty EVs, transit buses are the most mature application for medium- and heavy-duty fuel cell vehicles (FCVs). A 2018 NREL study scored hydrogen fuel cell electric buses (FCEBs)

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[128] *Id.*

[129] *Id.*

[130] *Id.*

[131] Couch et al., *2018 Feasibility Assessment for Drayage Trucks*, prepared for The Port of Los Angeles and Port of Long Beach, April 2019, available at: http://www.cleanairactionplan.org/documents/final-drayage-truck-feasibility-assessment.pdf/

[132] *Id.*

[133] *Id.*

[134] *Id.*

[135] https://www.energy.gov/sites/prod/files/2017/03/f34/fcto-energy-talks-2017-satyapal.pdf

with a Technological Readiness Level (TRL) of 7 to 8 out of 9, meaning that the buses have achieved full-scale validation in a relevant environment.[136] However, the report identifies lingering performance and administrative challenges related to fuel cell technology, including: balance of plant (e.g. compressors, fans, pumps) maintenance and supply issues, refueling issues related to compressor failure, lack of access to affordable hydrogen, and need for transit agency training.[137] According to the California Fuel Cell Partnership, 30 hydrogen buses are currently in operation and 22 hydrogen buses are in development in California.[138] There are two FCEB models currently eligible for HVIP incentives, both of which are manufactured by ElDorado National.[139]

Beyond transit buses, medium- and heavy-duty FCV deployment and demonstration projects have been primarily focused at ports and in parcel delivery applications in California.[140] Toyota, in partnership with Kenworth, is testing fuel cell powertrains for Class 8 drayage trucks in the Los Angeles region: 10 Kenworth T680 models outfitted with Toyota fuel cell technology will transport cargo from Ports of Los Angeles and Long Beach throughout the region and are expected to drive more than 300 miles per fill.[141] US Hybrid fuel cell drayage trucks were also piloted at the Port of Houston for three years with $6.4 million in funding.[142] Nikola Motors is currently in the demonstration phase of producing two fuel cell tractor models that are expected to reach mass production around 2025 with ranges upwards of 500 miles per fill.[143] NREL places hydrogen drayage trucks at a TRL level of 5 to 6 with the potential to move up to TRL 7 by 2021; however, TRL 8 – or commencing commercial production – does not seem likely before 2025.[144] This timeline may change as progress continues to be made for development of fuel cells for transit bus applications and fleet operators gain more experience deploying fueling stations.

Many of the challenges identified with the commercialization of FCVs revolve around access to hydrogen fuel, rather than the vehicles themselves.[145] The California Energy Commission (CEC) is currently making investments to support 100 hydrogen stations by fiscal year 2021-2022 pursuant to AB 8[146] and there are 40 retail hydrogen fueling stations operating in California, with 25 under development nationwide.[147] However, these stations are available to the public, do not provide unrestricted access to fleet operators looking to refuel their vehicles, and are not compatible with the fueling requirements for

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[136] https://www.nrel.gov/docs/fy19osti/72208.pdf

[137] *Id.*

[138] https://cafcp.org/by_the_numbers

[139] https://www.californiahvip.org/eligible-technologies/#your-clean-vehicles

[140] https://www.theicct.org/sites/default/files/publications/Zero-emission-freight-trucks_ICCT-white-paper_26092017_vF.pdf

[141] https://www.truckinginfo.com/330270/toyota-and-kenworth-unveil-jointly-developed-hydrogen-fuel-cell-truck

[142] https://www.theicct.org/sites/default/files/publications/Zero-emission-freight-trucks_ICCT-white-paper_26092017_vF.pdf

[143] Couch et al., *2018 Feasibility Assessment for Drayage Trucks*, prepared for The Port of Los Angeles and Port of Long Beach, April 2019, available at: http://www.cleanairactionplan.org/documents/final-drayage-truck-feasibility-assessment.pdf/

[144] *Id.*

[145] *Id.*

[146] https://www.energy.ca.gov/2017publications/CEC-600-2017-011/CEC-600-2017-011.pdf

[147] . https://afdc.energy.gov/stations/#/analyze?region=US-CA&fuel=HY

medium- and heavy-duty FCVs.[148] Shell (via Equilon) has announced plans to increase hydrogen station deployment at the Port of Long Beach with CEC funding to support its truck demonstration pilot.[149] Nikola recently announced plans to develop a network of 700 hydrogen stations across the U.S. and Canada by 2028 to support its vehicles;[150] for scale, only 65 public and private stations are operational today across the two countries.[151]

Overall, medium- and heavy-duty FCVs have the potential to be an important component of an alternative fuel vehicle strategy. However, the technology is still in a demonstration phase across a wide swath of vehicle applications, and more needs to be understood about the scalability of FCVs and associated hydrogen infrastructure. FCV advantages include quick fueling, efficiency, and long ranges, which may make them suited for longer-haul and drayage applications.[152] However, cost of fuel cell technology and hydrogen as well as the availability of hydrogen fueling infrastructure prove to be significant barriers to the widespread commercialization of this technology in the near-term.[153]

Emissions Impacts

FCVs produce zero tailpipe emissions, and instead emit only water vapor and warm air. Similar to electricity for EVs, hydrogen for FCVs can be produced from a number of processes and sources which impacts FCVs' well-to-wheels emissions. The most common process is natural gas reforming, which involves the use methane and thermal processes to create hydrogen gas. This process dilutes some of the emissions reductions benefits of FCVs: on a lifecycle basis, it may only reduce GHG emissions by 10% relative to diesel fuel in the U.S.[154] Hydrogen is increasingly being produced by electrolysis, which uses electricity to split water into hydrogen and oxygen; in California, that electricity is produced by increasingly cleaner generating resources, and state law requires that at least 33 percent of hydrogen produced at state-supported hydrogen stations must be produced with low-carbon resources.[155] The ICCT estimates that as hydrogen production becomes powered primarily be renewable energy resources, the carbon intensity of the fuel will be cut roughly in half by 2030.[156] Renewable liquid reforming and fermentation are other production methods that use biomass to produce hydrogen and may provide emissions reductions benefits relative to gas reforming methods.[157]

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[148] There may be limited private hydrogen fueling. https://afdc.energy.gov/stations/#/analyze?region=US-CA&fuel=HY

[149] https://www.bizjournals.com/losangeles/news/2018/04/20/toyota-shell-move-forward-with-hydrogen-facility.html

[150] https://www.forbes.com/sites/alanohnsman/2019/04/14/can-a-15-billion-bet-on-fuel-cell-big-rigs-be-a-game-changer-for-hydrogen/#27a373cfe4ce

[151] https://afdc.energy.gov/stations/#/find/nearest

[152] https://www.theicct.org/sites/default/files/publications/Zero-emission-freight-trucks_ICCT-white-paper_26092017_vF.pdf

[153] *Id.*

[154] https://www.theicct.org/sites/default/files/publications/Zero-emission-freight-trucks_ICCT-white-paper_26092017_vF.pdf

[155] https://www.ucsusa.org/sites/default/files/attach/2014/10/How-Clean-Are-Hydrogen-Fuel-Cells-Fact-Sheet.pdf

[156] https://www.theicct.org/sites/default/files/publications/Zero-emission-freight-trucks_ICCT-white-paper_26092017_vF.pdf

[157] https://afdc.energy.gov/fuels/hydrogen_production.html

Vehicle Costs

Concrete vehicle cost data is limited due to limited deployment of medium- and heavy-duty FCVs. In general, upfront FCV costs are still quite high, although they are beginning to decrease. In 2016, CARB estimated that FCEBs cost approximately $1.235 million.[158] The NREL FCEB assessment from 2018 reveals that recent bus orders cost $1.27 million, down from $2.5 million in 2010.[159] An order of 40 buses could push costs closer to $1 million per FCEB.[160] Truck cost data is difficult to obtain. Nikola anticipates offering an all-in truck cost, fueling, and maintenance package for around $900,000 over the million-mile life of the vehicle.[161] ICCT predicts that the TCO for heavy-duty FCVs may be 5%-30% less than diesel vehicles in 2030, but these assumptions are dependent on hydrogen fuel and infrastructure costs declining over time.[162]

Infrastructure Costs

Hydrogen fueling infrastructure cost is perhaps the most significant barrier to the development of the medium- and heavy-duty FCV market. The CEC estimates that the total cost of reaching its 100 station goal will approach $201.6 million, or over $2 million per station.[163] All-in costs, including installation and overhead, are around $2.5 million for 180 kg/day stations and up to $4 million for 360 kg/day stations. Costs for stations with greater capacity to fuel medium- and heavy-duty may be even higher: CEC awarded an $8 million grant to Shell for the development of one high-capacity hydrogen station at the Port of Long Beach.[164] Hydrogen stations are available in extremely low quantities today in California and are virtually nonexistent beyond California and several Northeastern states. As the U.S. Department of Energy notes, it is difficult to develop a comprehensive infrastructure network for distribution of hydrogen to hundreds or thousands of fueling stations.[165] Producing hydrogen on site may reduce distribution costs, but raises production costs if on-site production facilities are not already available. In short, the hydrogen station market has relied heavily on government support to grow, and the CEC identifies a strong need for private investment to achieve economies of scale and reduce costs in a manner that ultimately supports the self-sufficiency of the technology. The Port of Long Beach demonstration project will provide critical insights to the commercial viability and readiness of high-capacity hydrogen fueling stations – potentially leading to accelerated FCV deployments post-2021.[166]

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[158] http://www.caletc.com/wp-content/uploads/2019/01/Literature-Review_Final_December_2018.pdf

[159] https://www.nrel.gov/docs/fy19osti/72208.pdf

[160] *Id.*

[161] https://www.trucks.com/2019/04/17/nikola-unveils-trucks-launches-1-5-billion-investment-drive/

[162] https://www.theicct.org/sites/default/files/publications/Zero-emission-freight-trucks_ICCT-white-paper_26092017_vF.pdf

[163] https://www.energy.ca.gov/2017publications/CEC-600-2017-011/CEC-600-2017-011.pdf

[164] https://www.energy.ca.gov/business_meetings/2018_packets/2018-11-07/Item_18_ARV-18-002.pdf

[165] https://afdc.energy.gov/fuels/hydrogen_production.html

[166] Couch et al., *2018 Feasibility Assessment for Drayage Trucks*, prepared for The Port of Los Angeles and Port of Long Beach, April 2019, available at: http://www.cleanairactionplan.org/documents/final-drayage-truck-feasibility-assessment.pdf/

4 Scenario Analysis Methodology

This section describes the methodology for developing and analyzing alternative paths to clean vehicle and fuels implementation. The baseline (business as usual) and alternative paths are referred to as “scenarios”. This section describes the development of the analysis framework; the assumptions for fuel economy, emission factors, and costs; the emissions and costs results for the baseline scenario, and the process for creating the alternative scenarios.

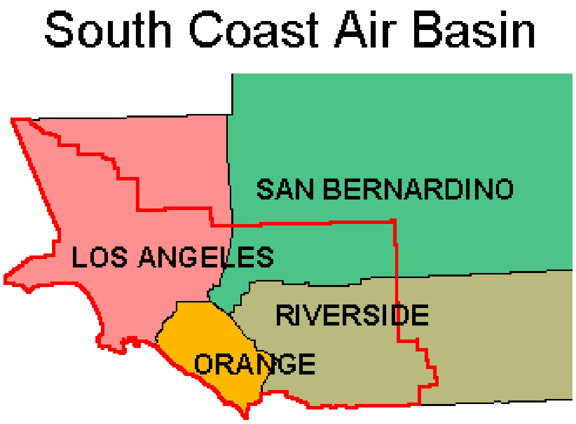
4.1 Analysis Framework

ICF developed an analysis tool for the purpose of quantifying the emissions and cost impacts of alternative paths to clean vehicle and fuels implementation. The tool characterizes a baseline scenario that reflects the vehicle population, travel activity, emissions, and costs assuming expected technology changes and implementation of all adopted rules and regulations, but no additional rules, regulations, or significant incentive programs. The tool then allows characterization of alternative scenarios that modify the baseline vehicle and fuel assumptions in order to explore the emissions and cost impacts of these scenarios. This section describes the development of the analysis framework.

Scope and Analysis Years

The analysis covers all on-road vehicles, including light, medium, and heavy-duty vehicles. No off-road vehicles or equipment are included in the analysis.

The focus of interest for this study is the portion of San Bernardino County that is within the South Coast Air Basin, illustrated to the right. The EMFAC model can provide vehicle population and activity data for this same geographic area. So all VMT and emissions data presented in this report reflect only the portion of San Bernardino County within the South Coast Air Basin.



The “base year” is the first calendar year included in the analysis, and is typically selected to be the most recent year for which observed (as opposed to projected) vehicle population and activity data exists. The base year for this analysis is 2016. This year was selected primarily because it is the base year in the California Air Resources Board’s (ARB) latest emissions model, EMFAC2017 – the primary source for vehicle population and activity data as described below.

Baseline Vehicle Categories and Populations

We obtained vehicle population and activity data from the EMFAC model. EMFAC is the model approved by the U.S. EPA for air quality planning purposes in California and is widely used for emissions analyses in the state. EMFAC is based on an extensive database of current and forecast vehicle information. Specifically, the model contains vehicle miles of travel (VMT) and emissions by:

- Geographic area
- Calendar year

- Vehicle type
- Fuel type
- Vehicle model year

Note that both the South Coast Air Quality Management District's Final 2016 Air Quality Management Plan (AQMP) and SCAG's Final 2016 Regional Transportation Plan and Sustainable Communities Strategy (RTP/SCS) relied on EMFAC2014, which was the model version available at the time of the plan analyses. Thus, these plans have a base year of 2012. EMFAC2017 was released on March 1, 2018, and it is therefore feasible to use this updated version of the model and a more recent base year. EMFAC2017 contains a number of updates and improvements compared to EMFAC2014, including:

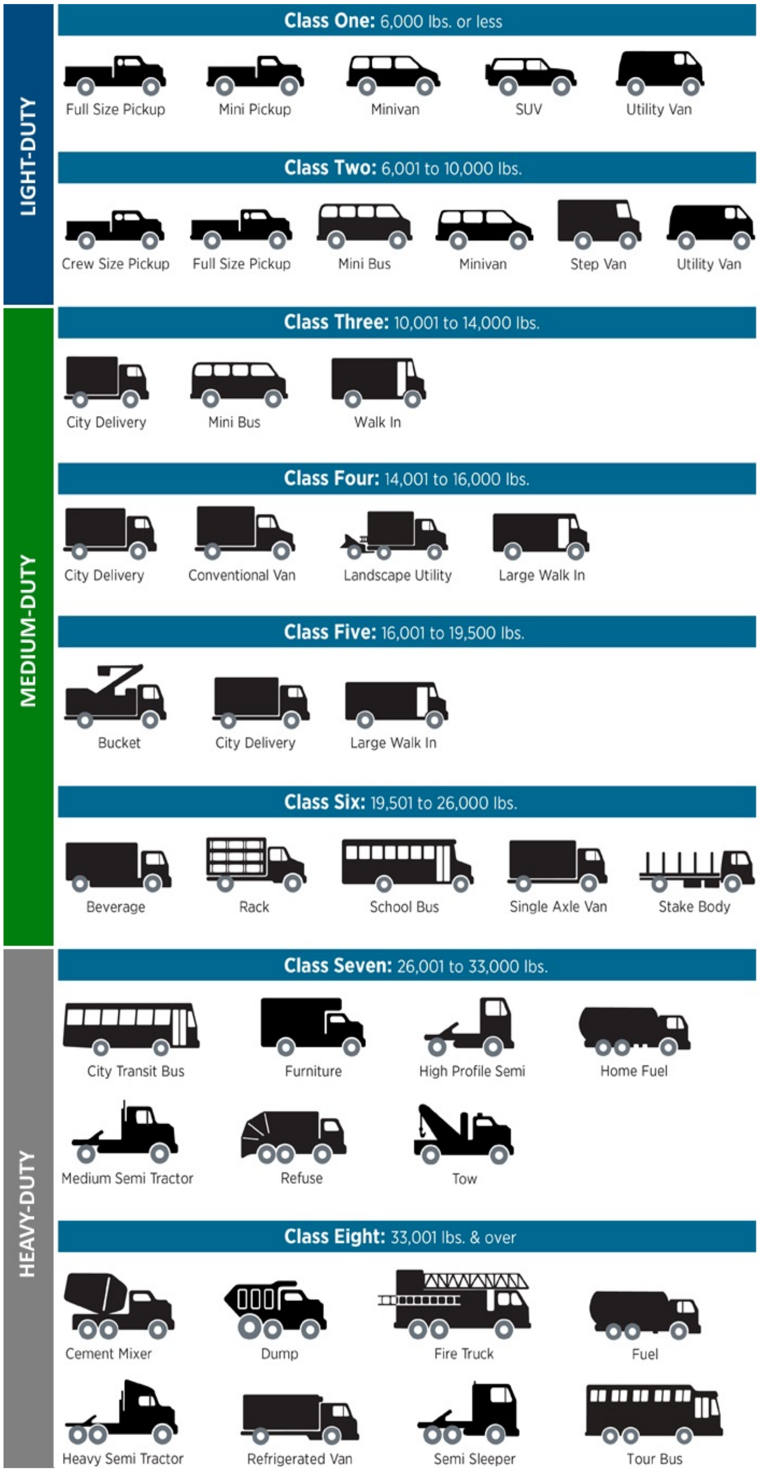
- While vehicle population in EMFAC2014 was based on 2000-2012 vehicle registration data from California Department of Motor Vehicles (DMV), EMFAC2017 uses DMV populations for years 2000 through 2016. The additional 4 years of DMV registration data (2013-2016) reflects the most recent changes to California motor vehicle fleet characteristics.
- EMFAC2017 uses the most recent International Registration Plan (IRP) data for characterizing out-of-state trucks and buses. Trucks that regularly travel in multiple states typically register with the IRP to facilitate payment of apportionable fees in multiple jurisdictions. ARB uses IRP data to help estimate the population and age distribution of out-of-state trucks that travel in California.
- EMFAC2017 updates the assumptions regarding how fleets are complying with the state Truck and Bus Rule requirements.
- For EMFAC2017, the Port of Los Angeles/Long Beach and the Port of Oakland provided lists of vehicle identification numbers (VINs) for vehicles that actually visited the ports, which has improved the model's characterization of port trucks.
- Emission factors have been updated for both light and heavy-duty vehicles.
- Updated socioeconomic factors are used to predict new vehicle sales and VMT growth trends.
- EMFAC2017 reflects the federal Phase 2 GHG standards, which were enacted in 2016.
- EMFAC2017 incorporates updates to assumptions regarding the state's Advanced Clean Cars (ACC) regulation based on the 2017 Midterm review of ACC. These include updates to Zero Emission Vehicle (ZEV) sales forecasts and updated carbon dioxide (CO2) emission rate and fuel efficiency forecasts.

Use of EMFAC2017 means that the base year emissions for this study are not exactly consistent with the existing AQMP or RTP/SCS. However, since the purpose of this study is primarily to identify effective emission reduction strategies and not directly for compliance or regulatory purposes, minor inconsistencies with the AQMP and RTP/SCS do not affect the study conclusions. Moreover, if we were to use EMFAC2014, the analysis would require that we make additional adjustments to EMFAC output to reflect the more recent regulations listed above.

Vehicle Categories

For the purpose of reporting results, we group vehicles into three major types – Light-Duty, Medium-Duty, and Heavy-Duty. These three major types, based on gross vehicle weight rating (GVWR), are commonly used by transportation agencies and the trucking industry, and are based on the eight vehicle classes developed by the Federal Highway Administration (FHWA). The figure below illustrates the three major vehicle types and the correspondence with the eight FHWA vehicle classes.

Figure 2. Types of Vehicles by Weight Class



Source: U.S. Department of Energy, Alternative Fuel Data Center, https://afdc.energy.gov/data/

EMFAC categorizes vehicles using a different system. The table below shows how we mapped by EMFAC vehicle categories to FHWA classes and major vehicle types.

Table 2. EMFAC Vehicle Categories

EMFAC Vehicle Category	EMFAC Description	FHWA Class	Vehicle Type
LDA	Passenger Cars	1	Light-Duty
LDT1	Light-Duty Trucks (GVWR <6000 lbs and ETW <= 3750 lbs)	1	Light-Duty
LDT2	Light-Duty Trucks (GVWR <6000 lbs and ETW 3751-5750 lbs)	1	Light-Duty
MDV	Medium-Duty Trucks (GVWR 6000-8500 lbs)	2	Light-Duty
LHD1	Light-Heavy-Duty Trucks (GVWR 8501-10000 lbs)	2	Light-Duty
LHD2	Light-Heavy-Duty Trucks (GVWR 10001-14000 lbs)	3	Medium-Duty
T6TS	Medium-Heavy Duty Gasoline Truck	4	Medium-Duty
T6 Public	Medium-Heavy Duty Diesel Public Fleet Truck	5	Medium-Duty
T6 utility	Medium-Heavy Duty Diesel Utility Fleet Truck	5	Medium-Duty
T6 Ag	Medium-Heavy Duty Diesel Agriculture Truck	6	Medium-Duty
T6 CAIRP small	Medium-Heavy Duty Diesel CA International Registration Plan Truck with GVWR<=26000 lbs	6	Medium-Duty
T6 instate construction small	Medium-Heavy Duty Diesel instate construction Truck with GVWR<=26000 lbs	6	Medium-Duty
T6 instate small	Medium-Heavy Duty Diesel instate Truck with GVWR<=26000 lbs	6	Medium-Duty
T6 OOS small	Medium-Heavy Duty Diesel Out-of-state Truck with GVWR<=26000 lbs	6	Medium-Duty
T6 CAIRP heavy	Medium-Heavy Duty Diesel CA International Registration Plan Truck with GVWR>26000 lbs	7	Heavy-Duty
T6 instate construction heavy	Medium-Heavy Duty Diesel instate construction Truck with GVWR>26000 lbs	7	Heavy-Duty
T6 instate heavy	Medium-Heavy Duty Diesel instate Truck with GVWR>26000 lbs	7	Heavy-Duty
T6 OOS heavy	Medium-Heavy Duty Diesel Out-of-state Truck with GVWR>26000 lbs	7	Heavy-Duty
PTO	Power Take Off	8	Heavy-Duty
T7 Ag	Heavy-Heavy Duty Diesel Agriculture Truck	8	Heavy-Duty
T7 CAIRP	Heavy-Heavy Duty Diesel CA International Registration Plan Truck	8	Heavy-Duty
T7 CAIRP construction	Heavy-Heavy Duty Diesel CA International Registration Plan Construction Truck	8	Heavy-Duty
T7 NNOOS	Heavy-Heavy Duty Diesel Non-Neighboring Out-of-state Truck	8	Heavy-Duty
T7 NOOS	Heavy-Heavy Duty Diesel Neighboring Out-of-state Truck	8	Heavy-Duty
T7 other port	Heavy-Heavy Duty Diesel Drayage Truck at Other Facilities	8	Heavy-Duty
T7 POAK	Heavy-Heavy Duty Diesel Drayage Truck in Bay Area	8	Heavy-Duty
T7 Public	Heavy-Heavy Duty Diesel Public Fleet Truck	8	Heavy-Duty
T7 Single	Heavy-Heavy Duty Diesel Single Unit Truck	8	Heavy-Duty
T7 single construction	Heavy-Heavy Duty Diesel Single Unit Construction Truck	8	Heavy-Duty
T7 SWCV	Heavy-Heavy Duty Diesel Solid Waste Collection Truck	8	Heavy-Duty
T7 tractor	Heavy-Heavy Duty Diesel Tractor Truck	8	Heavy-Duty
T7 tractor construction	Heavy-Heavy Duty Diesel Tractor Construction Truck	8	Heavy-Duty
T7 utility	Heavy-Heavy Duty Diesel Utility Fleet Truck	8	Heavy-Duty
T7IS	Heavy-Heavy Duty Gasoline Truck	8	Heavy-Duty
T7 POLA	Heavy-Heavy Duty Diesel Drayage Truck near South Coast	8	Heavy-Duty

The following EMFAC vehicle types were excluded from the analysis: Motor Coach, Other Buses, School Buses, Urban Buses, All Other Buses, Motor Homes, and Motorcycles. Because EMFAC breaks out VMT for out-of-state trucks that operate in the San Bernardino County study area, the analysis scenarios that focus on accelerated purchase of clean vehicle technologies (electric and natural gas) assume that these out-of-state trucks are unaffected, on the assumption that state and local stakeholders have less ability to influence these fleets. This is discussed below in the scenario analysis sections.

Vehicle Populations by Fuel Type

EMFAC presents data categorized by four fuel types:

- Gasoline
- Diesel
- Natural Gas
- Electric

The vehicles defined as "electric" are actually the portion of the fleet that will operate similar to pure zero emission vehicles (ZEVs). The electric portion is the sum of the populations of Battery Electric Vehicle (BEVs), Fuel Cell Electric Vehicles (FCVs) and the fraction of Plug-In Hybrid Electric Vehicles (PHEVs) that operate like pure ZEVs.[167] We separated the combined total into its individual components using a few key assumptions. The table below displays the assumed PHEV utility factor, defined by CARB as the fraction of VMT the PHEV obtains from the electrical grid.[168]

Table 3. Assumed PHEV Utility Factor by Model Year

Model Year	Utility Factor
<2018	0.46
2019	0.48
2020	0.50
2021	0.52
2022	0.54
2023	0.56
2024	0.58
2025+	0.60

The projected population of electric vehicles reflects compliance with the CARB ZEV mandate, based on the CARB Mid-Range Scenario of Advanced Clean Cars Midterm Review (Appendix A).[169, 170] We used the

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[167] https://ww3.arb.ca.gov/msei/downloads/emfac2017-volume-iii-technical-documentation.pdf
[168] https://ww3.arb.ca.gov/msei/downloads/emfac2017-volume-iii-technical-documentation.pdf
[169] https://www.arb.ca.gov/msprog/acc/mtr/appendix_a.pdf
[170] https://www.arb.ca.gov/msprog/zevprog/zevcalculator/zevcalculator_2017.xlsx

outputs of the Advanced Clean Cars modeling to calculate the percent of each vehicle type in the ZEV total. The table below presents the proportion of ZEVs attributed to each vehicle type, after accounting for the utility factor of PHEVs. The fossil fuel portion of PHEV was subtracted from the gasoline population and VMT data, making PHEVs a category of its own.

Table 4. Redistribution of ZEV

Calendar Year	PHEV	BEV	FCV
<2018	62.3%	29.8%	7.9%
2019	52.1%	37.1%	10.7%
2020	50.4%	38.2%	11.4%
2021	48.2%	39.4%	12.4%
2022	45.3%	36.8%	17.8%
2023	44.6%	36.8%	18.6%
2024	44.2%	36.5%	19.3%
2025+	44.0%	36.0%	20.0%

Fuel Economy

The assumed gasoline and diesel fuel economy for each vehicle type was calculated directly from EMFAC data by dividing fuel consumption by VMT. The fuel economy for natural gas, electric, and fuel cell vehicles were calculated by applying the energy economy ratio (EER) to the fuel economy of the gasoline or diesel vehicle of the same vehicle category. The EER is a dimensionless ratio that accounts for the differing energy efficiency of powertrains that use various fuels. For example, the electric vehicle fuel economy in DGE is equal to the diesel fuel economy multiplied by the electric EER. EER assumptions are shown in the table below.

Table 5. Energy Economy Ratios

Fuel	Light/Medium-Duty EER Relative to Gasoline	Heavy Duty EER Relative to Diesel
Gasoline	1.0	N/A
Diesel	N/A	1.0
Natural Gas	1.0	0.9
Electricity	3.4	5.0
Hydrogen	2.5	1.9

Source: CARB, *Analyses Supporting the Addition or Revision of Energy Economy Ratio Values for the Proposed LCFS Amendments*, 2018a. Available online at: https://www.arb.ca.gov/regact/2018/lcfs18/apph.pdf

The figures below display the weighted average fuel economy for new light and heavy duty vehicles over time, respectively.

Figure 3. New Light Duty Vehicle Fuel Economy (miles per gge)

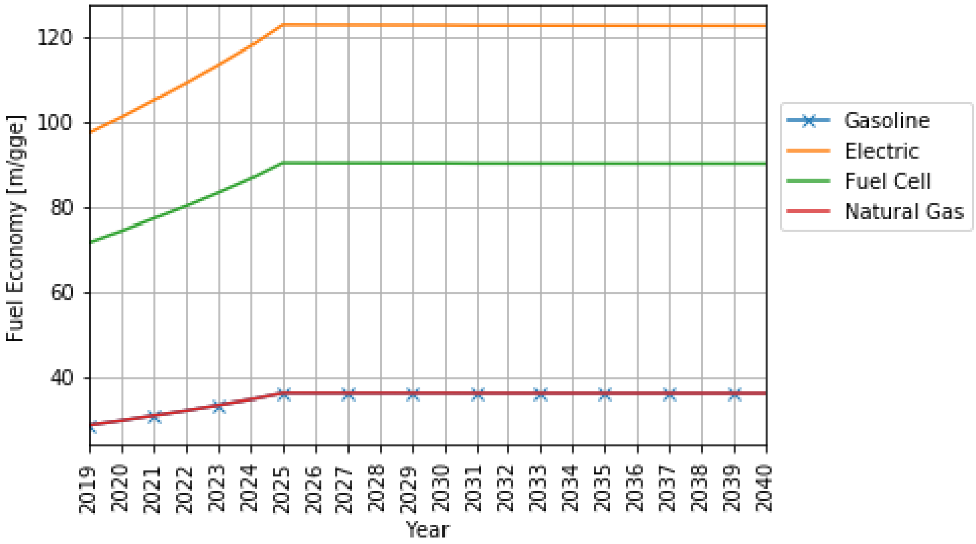
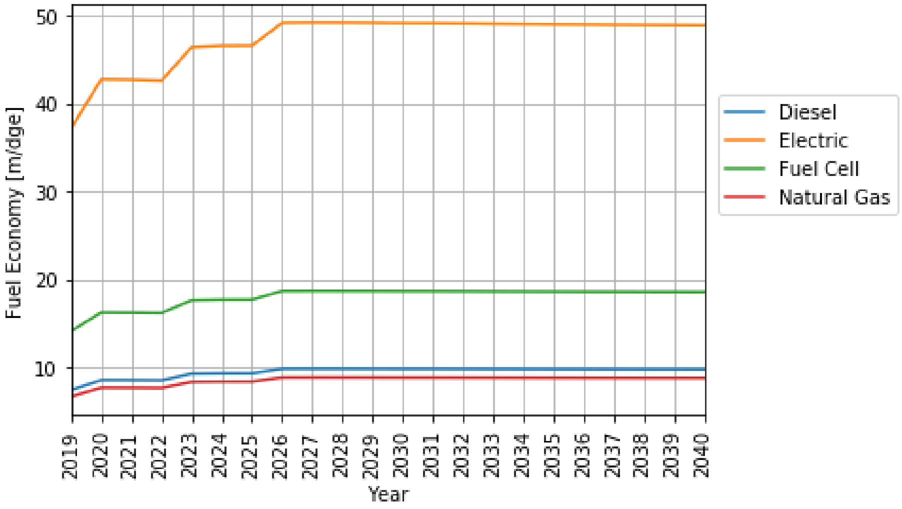


Figure 4. New Heavy Duty Vehicle Fuel Economy (miles per dge)



Emission Factors

Greenhouse Gas Emission Factors

Greenhouse gas emissions are calculated on a lifecycle basis using the carbon intensity (CI) values for each fuel type.

Fossil Fuels

The CI and energy density values for fossil fuels are displayed in the table below. These are default values from the Low Carbon Fuel Standard Final Regulation Order.

Table 6. Carbon Intensity of Fossil Fuels

Fuel	Description	Carbon Intensity (g CO_2e/MJ)	Energy Density
Gasoline	CARBOB-California Reformulated Gasoline Blendstock for Oxygenate Blending	100.82	119.53 MJ/gallon
Diesel	ULSD-Ultra Low Sulfur Diesel	100.45	134.47 MJ/gallon
Natural Gas	CNG- from Pipeline Average North American Fossil Natural Gas	79.21	105.5 MJ/Therm
Hydrogen	Compressed H2 from central SMR of North American fossil-based NG	117.67	120.00 MJ/kg

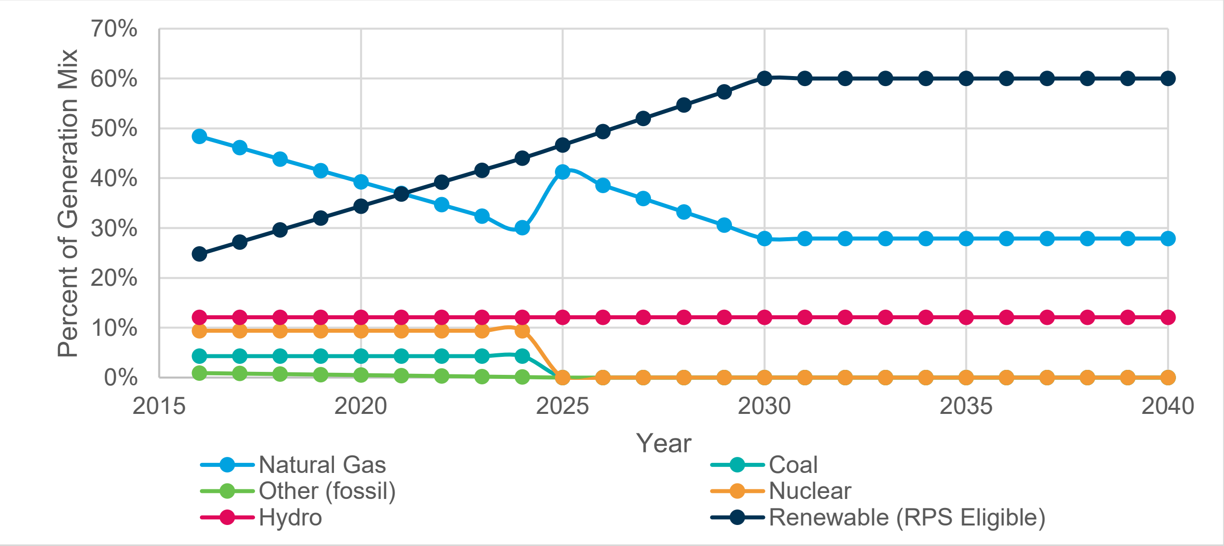
Source: CA LCFS Final Regulation Order, https://ww3.arb.ca.gov/fuels/lcfs/cleanfinalregorder112612.pdf

Electricity

For GHG emissions from electrified transport, we determined the current and future electrical grid carbon intensity values that take into consideration regional Renewable Portfolio Standard (RPS) requirements. The California-Mexico Power Area (CAMX) covers the San Bernardino County study area. The figure below shows the electricity generation resource mix by year, which is based on the following assumptions:

- Diablo Canyon nuclear facility to retire in 2025
- Coal power is retired by 2025 to meet RPS targets
- Oil and 'other' fossil fuels evenly decrease to 0% by 2025 to meet RPS targets
- Renewable RPS increase according to SB100 remaining constant at 60% from 2030 onward
- Renewable sources increase proportionally

Figure 5. Projected resource mix for the CAMX region based on RPS targets



The table below presents the results of the electricity emissions factor analysis, which is calculated using CA-GREET3.0 and based on the 2016 eGRID resource mix for the CAMX region and future RPS requirements. We assume energy density of electricity is 3.6 MJ/kWh.

Table 7. CAMX Region Projected Grid Carbon Intensity by Year

2016	2020	2025	2030	2035	2040
92.04	77.76	67.19	47.51	47.51	47.51

Biofuels

The lifecycle emission factors for biofuels vary greatly based on the feedstock and process used during production. The table below shows the wide variation in carbon intensity values for biofuels depending on the feedstock and production process.

Table 8. Carbon Intensity Values for Various Biofuels

Fuel	Feedstock	Emissions Factors (gCO2e/MJ)	
		Low	High
Ethanol		20.00	72.04
	Corn	63.90	75.97
	Sorghum	63.90	83.49
	Sugarcane	35.50	56.66
	Corn stover	41.05	41.05
	Cellulosic	20.00	20.00
Renewable Gasoline		15.00	35.00
Biodiesel		10.00	39.32
	Soybean oil	42.03	51.85
	Corn oil	5.00	10.00
	Canola oil	40.19	57.87
	Animal fats	15.00	37.54
Renewable Diesel		20.00	40.00
Renewable Natural Gas		7.85	55.53
	LFG, CNG	15.00	46.42
	LFG, LNG	20.00	64.63
	High solids anaerobic digestion (HSAD)		-22.93
	Waste water treatment		19.34

Source: Fuel pathways submitted for California’s Low Carbon Fuel Standard

The baseline emission factors for biofuels used in the analysis are based on the average CI in 2018 as published by the Low Carbon Fuel Standard quarterly reporting.[171] Similarly, the percent of the Baseline Scenario total fuel consumption replaced with biofuels was calculated based on the fuel volumes reported.

Table 9. Biofuel Emissions Factors and Percent of Total Volume

Renewable Fuel	2018 Average Carbon Intensity (g CO2e/MJ)	Fuel Replaced	Percent of Total Demand
Ethanol	68.60	Gasoline	10%
Biodiesel	31.05	Diesel	5%
Renewable Diesel	32.17	Diesel	10%
Renewable Natural Gas	40.94	CNG	71%
Renewable Hydrogen	99.48	Compressed H_2	0%

Note: Default CI value for compressed hydrogen produced in California from central SMR of biomethane (renewable feedstock) from North American landfills.

NOx Emission Factors

Diesel & Gasoline Vehicles

For gasoline and diesel vehicles, tailpipe emission factors were taken directly from EMFAC2017. The emission factors are unique to each vehicle class, fuel type, model year, and calendar year. The tailpipe emission factors for NOx used in this model include:

- Running Exhaust Emissions (RUNEX) that come out of the vehicle tailpipe while traveling on the road.
- Idle Exhaust Emissions (IDLEX) that come out of the vehicle tailpipe while it is operating but not traveling any significant distance (for example, heavy-duty vehicles that idle while loading or unloading goods).
- Start Exhaust Tailpipe Emissions (STREX) that occur when starting a vehicle

The table below shows NOx emission factors for select vehicle types for 2019, 2030, and 2040. The analysis includes emission factors for each vehicle category in EMFAC, listed in Table 2. Rather than show emission factors for all vehicle categories and fuel types (more than 50), this report shows three representative vehicle types from the EMFAC model: LDA (light duty automobile, a typical light-duty vehicle), T6 Small Instate (a typical medium-duty vehicle), and T7 Tractor (a typical heavy-duty vehicle). These vehicle types were selected because they comprise a significant share of the vehicles within their given weight class.

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[171] https://ww3.arb.ca.gov/fuels/lcfs/lrtqsummaries.htm

NOx emission rates are much higher for diesel vehicles. Running NOx emission rates drop significantly between 2019 and 2030 as older vehicles (those that do not meet with 2010 emission standards) are retired from the fleet. There is little change in Baseline NOx emission rates between 2030 and 2040.

Table 10: NOx Emission Factors for Representative Vehicle Types, aggregated model years

		Idle (g/trip)				Running (g/mile)				Start (g/trip)		
Vehicle Type	**Fuel**	**2019**	**2030**	**2040**		**2019**	**2030**	**2040**		**2019**	**2030**	**2040**
LDA	Gasoline	0.000	0.000	0.000		0.057	0.021	0.018		0.025	0.015	0.014
T6 instate small	Diesel	0.139	0.060	0.063		3.148	1.096	1.110		0.264	0.522	0.544
T7 tractor	Diesel	0.202	0.192	0.179		5.438	2.248	2.115		0.099	0.205	0.192

CNG Vehicles

For the scenario calculations, all new CNG vehicles are assumed to have a Low-NOx natural gas engine. These engines are certified at 0.02 grams per brake horsepower-hour (g/bhp-hr), which is a 90 percent reduction from the current heavy-duty vehicle standard of 0.2 g/bhp-hr. In our analysis framework, the NOx emissions factors for new CNG vehicles are assumed to be 10 percent of the emissions factor of the diesel vehicle it is replacing.

Electric & Fuel Cell Vehicles

Electric and fuel cell vehicles are assumed modeled to have zero tailpipe NOx emissions.

PM2.5 Emission Factors

Diesel & Gasoline Vehicles

For fine particular matter (PM2.5), gasoline and diesel vehicle tailpipe emission factors were taken directly from EMFAC2017. The emission factors are unique to each vehicle class, fuel type, model year, and calendar year. The tailpipe emission factors for PM2.5 used in this model include:

- Running Exhaust Emissions (RUNEX) that come out of the vehicle tailpipe while traveling on the road.
- Idle Exhaust Emissions (IDLEX) that come out of the vehicle tailpipe while it is operating but not traveling any significant distance (for example, heavy-duty vehicles that idle while loading or unloading goods).
- Start Exhaust Tailpipe Emissions (STREX) that occur when starting a vehicle.
- Tire Wear Particulate Matter Emissions (PMTW) that originate from tires as a result of wear.
- Brake Wear Particulate Matter Emissions (PMBW) that originate from brake usage.

The table below shows PM2.5 emission factors for select vehicle types for 2019, 2030, and 2040. As with NOx emission factors, the table shows only three representative vehicle types, although the analysis includes PM2.5 emission factors specific to each EMFAC vehicle category and fuel. Like NOx emission factors, PM2.5 emission rates are much higher for diesel trucks than gasoline automobiles. For gasoline autos, PM2.5 emissions come primarily from brake wear, not exhaust. PM2.5 emission rates are expected to decline significantly between 2019 and 2030 as older vehicles are retired, then change little between 2030 and 2040. In the later years of the analysis, exhaust PM emission rates become lower than brake wear emission rates.

Table 11: PM2.5 Emission Factors for Representative Vehicle Types, aggregated all model years

		Brake Wear (g/mile)				Exhaust (g/mile)				Tire Wear (g/mile)		
Vehicle Type	**Fuel**	**2019**	**2030**	**2040**		**2019**	**2030**	**2040**		**2019**	**2030**	**2040**
LDA	Gasoline	0.016	0.016	0.016		0.002	0.001	0.001		0.002	0.002	0.002
T6 instate small	Diesel	0.056	0.056	0.056		0.111	0.007	0.007		0.003	0.003	0.003
T7 tractor	Diesel	0.026	0.026	0.026		0.102	0.020	0.018		0.009	0.009	0.009

CNG Vehicles

For the scenario calculations, all new CNG vehicles are assumed to have a Low- NOx certified engine. All new CNG vehicles were assumed to have a PM2.5 running exhaust emission factor of 0.0005 g/mile based on a previous study prepared by ICF for NextGen Climate America and the Union of Concerned Scientists.[172] The tire and brake wear emissions factors for CNG vehicles were assumed to be equivalent to the diesel vehicle they are replacing.

Electric & Fuel Cell Vehicles

Electric and fuel cell vehicles were modeled to have zero running, idling, and starting tailpipe PM2.5 emissions factors. Electric vehicles still have PM emissions from tire and brake wear. EVs have lower brake wear emissions than comparable gasoline and diesel vehicles because the use of regenerative braking reduces brake use. For this analysis, we assume electric vehicles emissions for brake wear to be 50 percent of the vehicle emissions they are replacing.

Cost Assumptions

To evaluate the total costs associated with each scenario modeled, ICF developed estimates for the following cost categories:

- Vehicle purchase costs
- Fuel costs
- Fueling infrastructure costs
- Maintenance costs (for vehicles and infrastructure)

These categories reflect the capital, operations, and maintenance costs associated with incorporating alternative fuel vehicles into the on-road fleet, providing a means to compare the costs and savings associated with the adoption of various vehicle technologies. Cost assumptions are primarily adopted from publicly available government datasets, tools, and publications. These cost per unit assumptions are held constant across all the scenarios evaluated.

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[172] ICF International, *Half the Oil: Pathways to Reduce Petroleum Use on the West Coast*, Prepared for NextGen Climate America and the Union of Concerned Scientists, 2016.

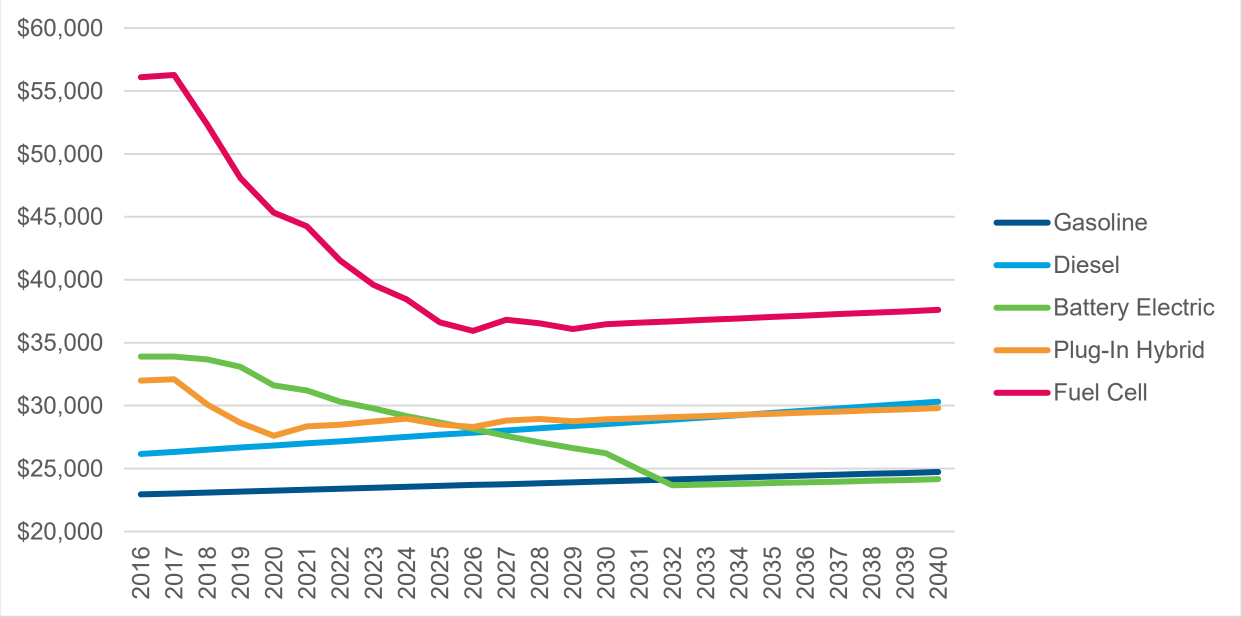
Vehicle Purchase Costs

Vehicle purchase costs can vary significantly across and within vehicle weight classes. Vehicles within the weight same class may also exhibit diverse costs depending on their fuel types. We developed estimates of current and future vehicle purchase prices primarily from CEC's *Transportation Energy Demand Forecast, 2018-2030*[173] and ICF's analysis for the California Electric Transportation Coalition (CalETC).[174] The CalETC analysis relies on estimates of price curves for truck battery packs produced by Bloomberg New Energy Finance, a literature review, and interviews with current battery electric truck manufacturers. Purchase price assumptions vary by weight class and fuel type. As with the emission rates above, to illustrate these assumptions, below we show the assumptions for three representative vehicle types from the EMFAC model: LDA (a typical light-duty vehicle), T6 Small Instate (a typical medium-duty vehicle), and T7 Tractor (a typical heavy-duty vehicle). These vehicle types were selected because they comprise a significant share of the vehicles within their given weight class.

Light-Duty Vehicles

LDA vehicle costs are broken out by fuel type in the figure below and derived from the CEC's *Transportation Energy Demand Forecast, 2018-2030.* The forecast provides key data on vehicle and fuel trends in California, which are used to support the CEC's Integrated Energy Policy Reports and inform the State's approach to energy policymaking.

Figure 6. Vehicle Purchase Costs by Fuel Type (LDA, or typical LDV)



Gasoline light duty auto vehicle prices increase gradually from $23,000 in 2016 to $25,000 in 2040. LDA BEVs start at approximately $34,000 in 2016 but drop steadily due primarily to the expected decline in battery costs. By 2032, LDA BEVs are assumed to have a slightly lower purchase price than gasoline

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[173] https://efiling.energy.ca.gov/getdocument.aspx?tn=221893

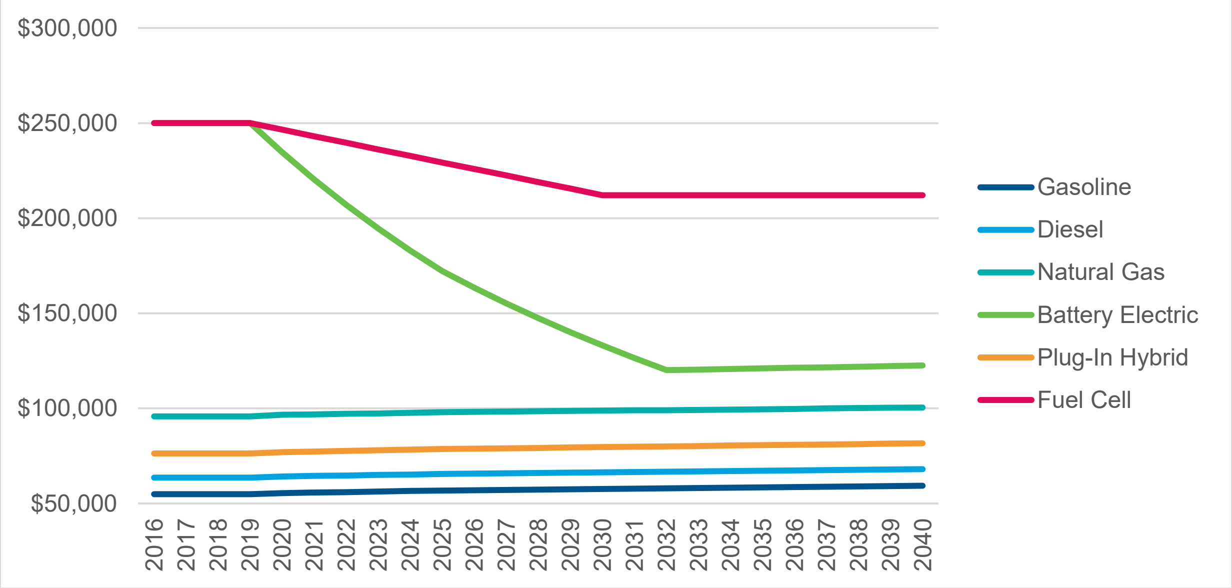
[174] ICF, Total Cost of Ownership Assessment for Medium and Heavy Duty Technologies in California, prepared for California Electric Transportation Coalition (CalETC), 2019.

vehicles. PHEVs start off modestly cheaper than BEVs, but then cross over by the mid-2020s and increase moderately to $30,000 in 2040. LDA FCVs remain the most expensive vehicle type throughout the analysis period, despite significant cost declines in throughout the 2020s. Overall, gasoline LDA vehicles remain the most competitive vehicle type on an upfront cost basis until the early 2030s when BEVs become the lowest-cost vehicle type.

Medium-Duty Vehicles

Purchase price assumptions for MDVs were are adapted from ICF's analysis for CalETC.[175] The figure below shows the purchase price assumptions for a representative MDV. Diesel vehicles in this class cost approximately $63,000 in 2016, increasing marginally to $68,000 in 2040. NGVs start at $95,000 in 2016 and experience similar cost escalation through 2040. EVs costs are expected to decline 50 percent between 2016 and 2040 as battery technologies improve. Similarly, FCV costs are projected to decrease from a $250,000 peak in 2016 and reach $180,000 in 2040. Throughout the analysis period, gasoline and diesel remain the lowest MDV in terms of vehicle cost.

Figure 7. Vehicle Purchase Costs by Fuel Type (T6 Small Instate, or typical MDV)



Heavy-Duty Vehicles

HDV costs are also adopted from ICF's analysis for CalETC. Diesel T7 tractor trucks are assumed to cost $110,000 in 2016 and escalate steadily to $120,000 in 2040. Natural gas and plug-in hybrid trucks experience similar cost increases – albeit from a higher initial purchase price. Battery electric truck costs start at $250,000 in 2016, but significant cost decreases through the 2020s bring vehicle costs to levels comparable to diesel trucks. Fuel cell trucks also experience notable cost declines and are estimated to reach approximately $130,000 in 2040.

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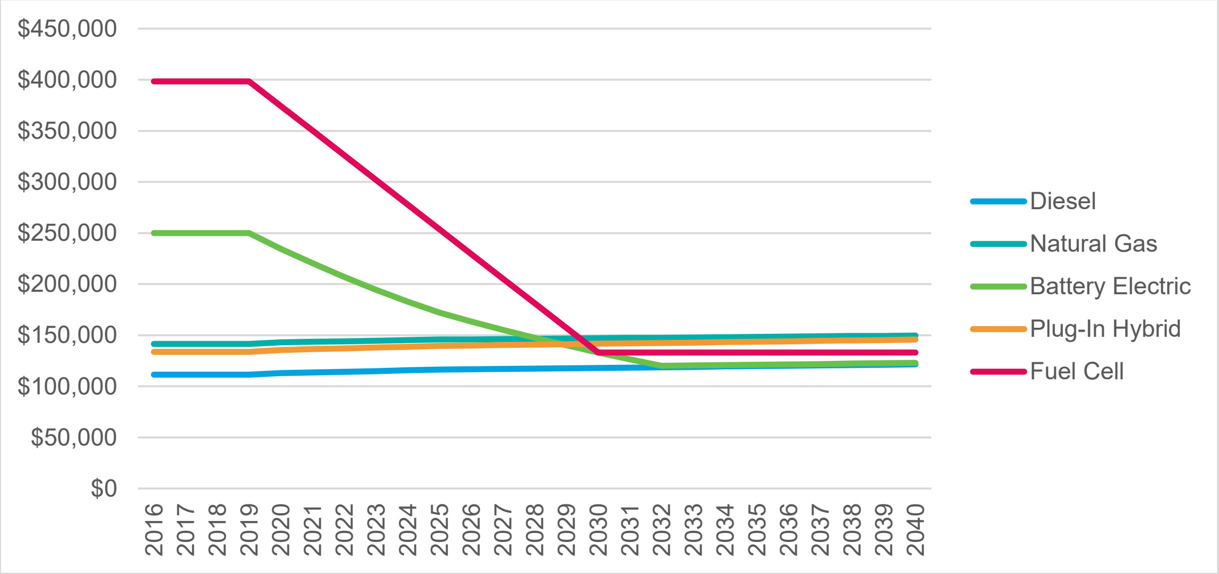
[175] ICF, Total Cost of Ownership Assessment for Medium and Heavy Duty Technologies in California, prepared for California Electric Transportation Coalition (CalETC), 2019.

Figure 8. Vehicle Purchase Costs by Fuel Type (T7 Tractor, or typical HDV)



Fuel Costs

Fuel cost assumptions for gasoline, diesel, natural gas, and hydrogen are derived from CEC's *Revised Transportation Energy Demand Forecast, 2018-2030*.[176] For years 2031-2040, ICF extrapolated CEC's fuel cost estimates to follow DOE's Annual Energy Outlook trends.[177] The figure below illustrates estimated fuel prices for gasoline, diesel, and natural gas on a gallon-equivalent basis from 2016-2040.

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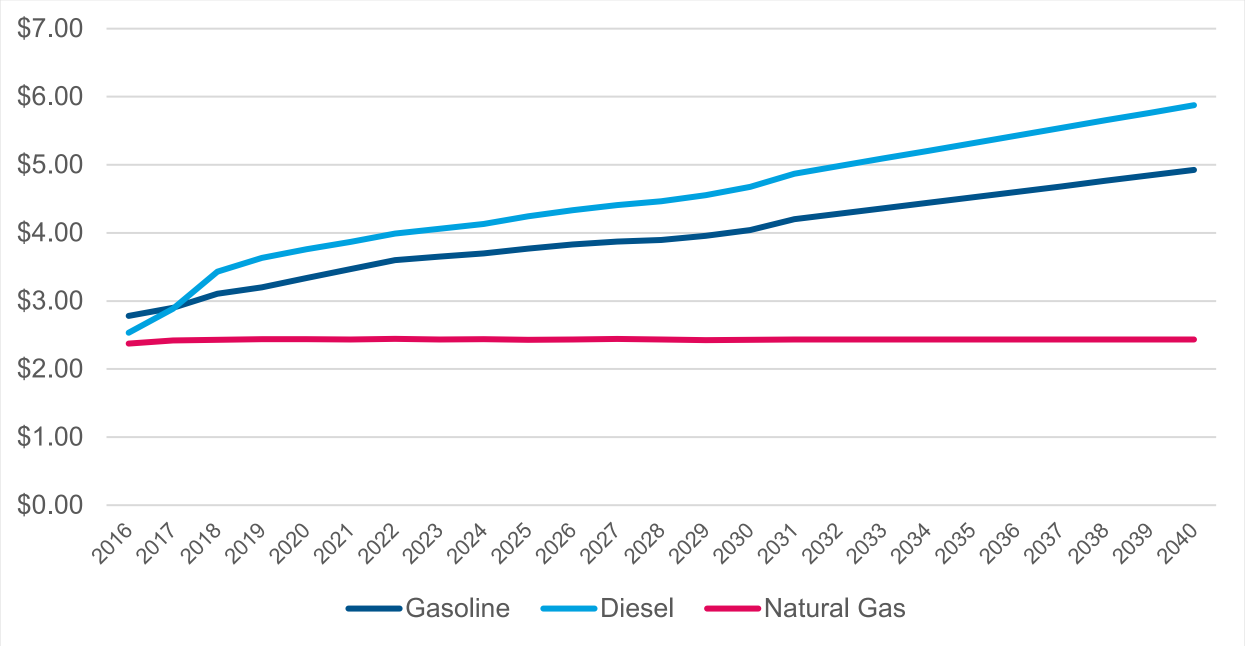
[176] https://efiling.energy.ca.gov/GetDocument.aspx?tn=223241

[177] https://www.eia.gov/outlooks/aeo/pdf/aeo2019.pdf

Figure 9. Fuel Cost Assumptions: Gasoline, Diesel, and Natural Gas Prices per Gallon Equivalent



Gasoline and diesel prices start below $3 per gallon in 2016 and gradually increase through 2040 to nearly $6 per gallon and $5 per gallon, respectively. Gasoline prices surpass $4 per gallon in 2022 while diesel prices do not exceed $4 per gallon until approximately 2030. Natural gas prices are assumed to remain flat near $2.50 per gallon-equivalent throughout the analysis period.

The CEC finds that hydrogen prices were approximately $15.50 per gallon of gasoline equivalent (GGE) in 2016. However, unlike other transportation fuels, hydrogen prices are expected to decline gradually through 2030 to approximately $10 per GGE in CEC's Mid Demand Scenario due to economies of scale resulting from increased hydrogen production.[178] Hydrogen costs are expected to decline an additional $2 between 2031-2040 to $8 per gallon of gasoline equivalent and are not projected to reach cost parity with gasoline on a GGE basis.

Electricity costs are derived from Southern California Edison's (SCE) residential and commercial electricity tariffs: TOU-EV-1 and TOU-EV-8, respectively.[179] Both tariffs are time-of-use rates, which vary depending the time of day that an EV draws power and are based on electricity (per kilowatt-hour) consumption. Rates are higher during "on-peak" periods when the electricity system typically experiences high demand and lower during "off-peak" periods when spare capacity is more available on the grid. While "per gallon-equivalent" prices will vary depending on when EV charging occurs, electricity costs are generally lower than relative to gasoline and diesel. For example, a light-duty EV charging on off-peak on SCE's TOU-EV-1 rate can experience fuel costs as low as $1 per gallon.[180]

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[178] https://efiling.energy.ca.gov/GetDocument.aspx?tn=223241

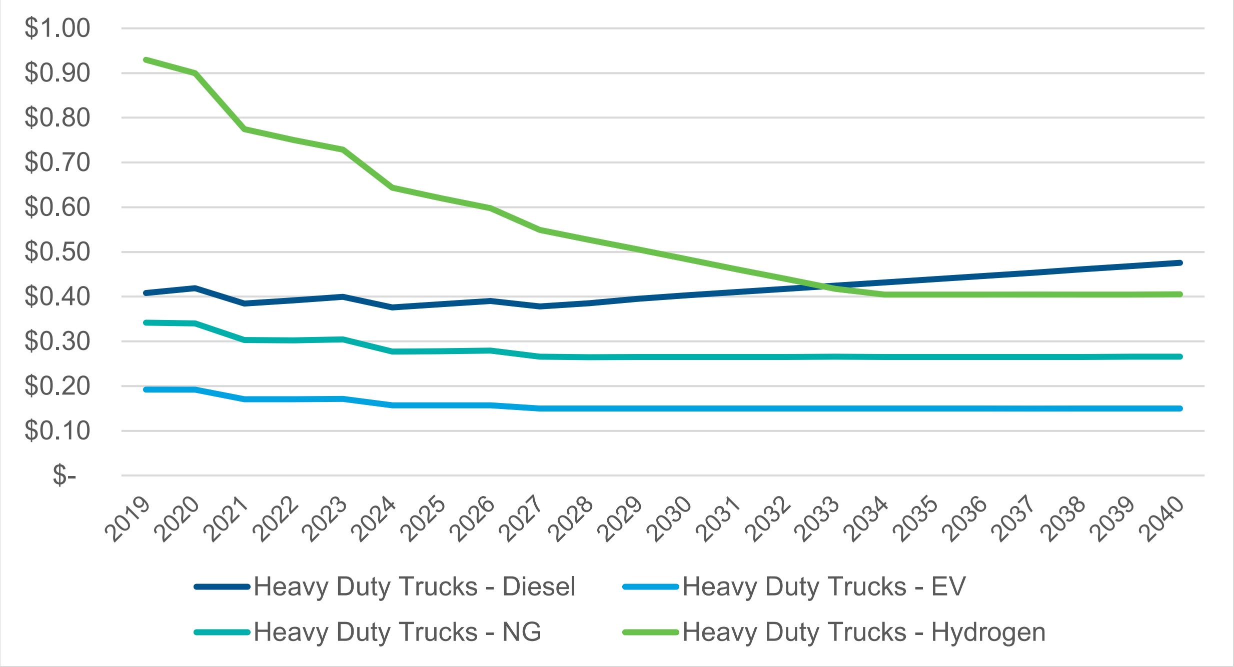
[179] https://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=6442457781

[180] Assumes the TOU-EV-1 off-peak rate of $0.13 per kWh, EV efficiency of .27 kWh per mile, and comparable gasoline vehicle efficiency of 28.6 miles per gallon.

Commercial utility customers are also traditionally subject to demand charges, which are collected based on customers' instantaneous electricity demand (per kilowatt) and often challenge the economics of DCFC station operations due to their high electricity *demand* but relatively low electricity *consumption*. In other words, DCFC station operators typically have little opportunity to recoup operational costs through revenue from EV charging at current station utilization rates. To encourage EV adoption while ensuring "just and reasonable" rates[181], the California Public Utilities Commission-approved TOU-EV-8 rate temporarily substitutes demand charges for energy charges for five years and gradually re-introduces demand charges over an additional five years as EV adoption increases. This adjustment is expected to improve the economics of fueling EVs – including medium- and heavy-duty EVs that may rely almost exclusively on fast charging.

Fuel costs directly affect cost per vehicle mile traveled, a salient factor in fleet managers' decisions to procure alternative fuel vehicles. The figure below illustrates the fueling cost per mile of all HDVs based on their VMT-weighted average fuel economy. Per mile electricity fueling costs remain lowest throughout the analysis period, starting at nearly $0.20 per mile and declining to approximately $0.15 per mile in 2040. Costs per mile for natural gas trucks were consistently second-lowest in the analysis, declining marginally through 2040. Cost per mile for diesel-fueled trucks remain near $0.40 per mile through 2030, but due to increasing diesel costs and declining hydrogen fuel costs, hydrogen fuel becomes more competitive on a cost per mile basis relative to diesel around 2033 and remains near $0.40 per mile through 2040.

Figure 10. VMT-Weighted Cost per Mile of HDVs by Technology



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[181] Public Utilities Code section § 451 requires that the CPUC determine whether a utility's proposed rates, services, and charges are just and reasonable.

Fueling Infrastructure Costs

Alternative fuel vehicles rely on the deployment of diverse types of refueling infrastructure with varying levels of cost. These costs are typically broken out into equipment costs, installation costs, and operation costs.

For light-duty vehicles, gasoline blended with 15 percent ethanol (E15) provides a drop-in alternative to conventional gasoline with the provision of additional infrastructure. Signage, underground storage tanks (UST), and new or converted dispensers are needed to support E15 fueling. Converting a dispenser at a gas station to E15 without installing a new UST is approximately $4,800; a new UST costs $115,000. Diesel blended with 20% biofuel (B20) can similarly be used as a drop-in fuel for diesel engines and requires similar infrastructure upgrades at conventional diesel fueling stations. Total conversion costs for four dispensers are assumed to be approximately $75,000.

New natural gas stations that are capable of dispensing one million diesel gallon equivalent (DGE) per year are estimated to cost $1 million. On top of this $1 million capital expenditure, these station installation costs are projected to be $1 million per station with annual operation costs at $115,000 per year. These figures are expected to remain constant throughout the analysis period and are derived from DOE's *Costs Associated With Compressed Natural Gas Vehicle Fueling Infrastructure*.[182]

Hydrogen fueling stations for light-duty vehicles cost an estimated $2.8 million per station. Installation costs comprise an additional $1 million and annual station operating expenses reach approximately $150,000. These costs are expected to remain constant throughout the analysis period and are derived from CEC's staff report on Assembly Bill 8.[183]

EV charging station deployment costs can vary widely depending on the throughput of the station, amount of available electrical capacity at the site, charging station features and software, and other factors. Residential L2 charging station and installation costs are expected to be $1,200 throughout the analysis period. Non-residential L2 station hardware and installation costs amount to approximately $9,500, with operational costs reaching $1,200. 50 kilowatt DCFC station hardware and installation costs are expected to remain near $75,000 with an additional $2,500 devoted to operational expenses. Comparable hardware and installation costs for 200 kW DCFC stations are expected to be $105,000, with $5,500 dedicated to operational costs. However, hardware costs are expected to decline from $50,000 to $25,000 in 2030 and remain unchanged through 2040, suggesting that production costs for fast charging will decrease as more DCFC stations are deployed. The table below summarizes the primary cost drivers for each fueling infrastructure type. Residential L2 chargers, non-residential L2 chargers, and non-residential DCFC stations are used by light-duty vehicles whereas 19 kW, 40 kW, 100 kW, and 200 kW chargers are used for medium- and heavy-duty vehicles.

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[182] https://afdc.energy.gov/files/u/publication/cng_infrastructure_costs.pdf

[183] https://ww2.energy.ca.gov/2015publications/CEC-600-2015-016/CEC-600-2015-016.pdf

Table 12. Fueling Infrastructure Installation and Equipment Costs

Fuel	Station Capacity	Amt. (AFDC)	Lifetime (AFLEET)	Installation Cost	Cost per Station
Natural Gas	1 million DGE/year	15-20	5-12	$1,000,000	$1,000,000
Hydrogen	230 kg/day	0	20	$1,000,000	$2,800,000
Residential L2 chargers	1 vehicle/ station	N/A	N/A	$3,000	$400-$6,500
Non-residential L2 chargers	1 vehicle/station	103	7	$3,000	$400-$6,500
Non-residential DCFC	2 vehicles/station	34	10	$21,000	$20,000-$36,000
19 kW Charger	2 vehicle/station	0	20	$20,000	$5,000
40 kW Charger	2 vehicle/station	0	20	$20,000	$8,000
100 kW Charger	2 vehicle/station	0	20	$50,000	$20,000
200 kW Charger	2 vehicle/station	0	20	$55,000	$50,000
Conversion to E15 Station	4-6	2	20+	NA	$119,800-$146,000
Conversion to B20 Station	4-6	0	20+	NA	$45,500

Maintenance Costs

Estimates of vehicle maintenance costs come from Argonne National Laboratory's Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) Tool's default maintenance values. AFLEET is commonly used to assess the emissions from and costs of operating vehicles via payback calculators and total cost of ownership calculators.[184] Key inputs to the tool include vehicle location, type, fuel type, annual mileage, fuel economy, vehicle purchase price, and fuel prices. Maintenance costs include brake maintenance, oil changes, treatments or additives, scheduled inspections, and other repairs. The table below illustrates the total maintenance costs per mile by fuel type for the three representative vehicle classes: LDA, T6 Instate Small, and T7 Tractor. Maintenance costs per mile are assumed to remain constant over time.

Table 13. Maintenance Cost per VMT

Vehicle Type \ Fuel Type	Gasoline	Diesel	Natural Gas	BEV	PHEV	FCV
LDA (typical LDV)	$0.14	$0.19	N/A	$0.13	$0.13	$0.13
T6 Instate small (typical MDV)	N/A	$0.19	$0.19	$0.17	$0.16	$0.17
T7 Tractor (typical HDV)	N/A	$0.19	$0.19	$0.17	$0.16	$0.17

Key: BEV = battery electric vehicle, PHEV = plug-in hybrid vehicle, FCV = fuel cell vehicle

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[184] https://greet.es.anl.gov/afleet_tool

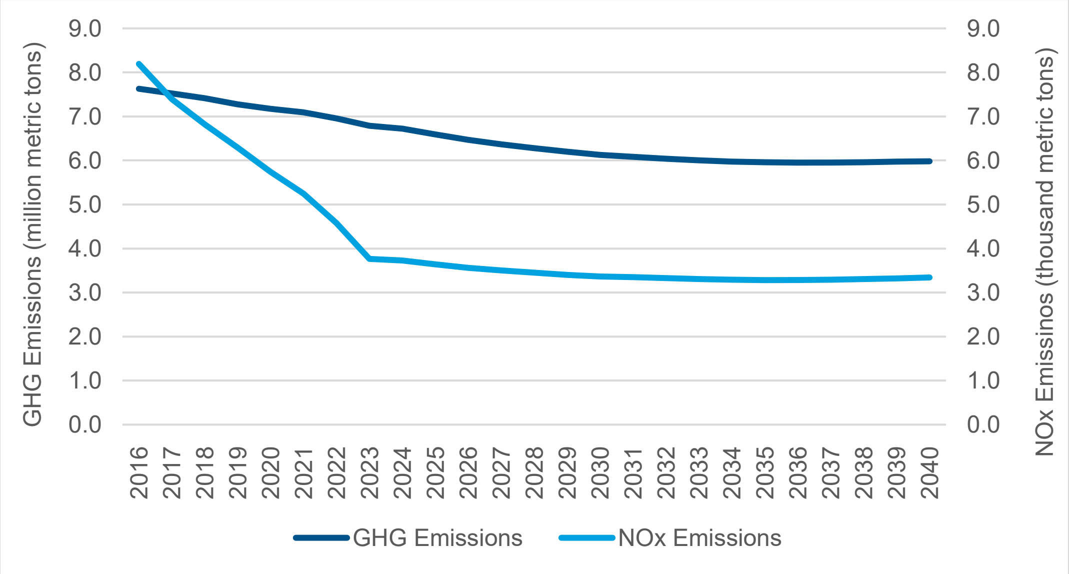
LDA vehicles exhibit the widest variation in maintenance cost between fuel types, with diesel and BEVs forming the upper and lower cost bounds for this vehicle class. Maintenance costs for T6 Instate Small and T7 Tractor vehicles do not vary significantly; however, BEV and FCV costs remain slightly less expensive on a per mile basis than comparable fossil-fuel vehicles.

4.2 Baseline Results

This section summarizes the Baseline Scenario, which serves as the reference scenario for comparison against the clean vehicle and fuels scenarios describe in the next section. As noted previously, the Baseline Scenario and all other scenarios reflect only the VMT and emissions within the South Coast Air Basin portion of San Bernardino County. The Baseline Scenario reflects the implementation of all rules and regulations that had been adopted at the time of the analysis (fall 2019), but not additional regulations or significant incentive programs. So, for example, the Baseline Scenario does not reflect CARB’s Advanced Clean Truck regulation, which was not yet adopted at the time of this analysis; many of the assumptions in that regulation are reflected in the Electrification Scenario discussed later.

As an overview of the Baseline Scenario, the figure below shows the baseline on-road vehicle GHG and NOx emissions in the study area. Over the analysis period, while the total vehicle population is expected to grow by 54 percent, NOx emissions will decline by 59 percent and GHG emissions will decline by 22 percent. The sharp decline in NOx emissions between 2016 and 2023 is primarily due to the retirement of older trucks that do not meet the latest emission standards, driven by the CARB Statewide Truck and Bus Rule. After 2023, NOx emissions are relatively flat, as the slow introduction of cleaner vehicles and fuels is offset by growth in the vehicle population and VMT. GHG emissions from on-road vehicles in the study area are projected to decline gradually until around 2030, due to natural fleet turnover and the introduction of more fuel efficient vehicles couple with growing use of low carbon fuels, After 2030, GHG emissions remain flat, as growth in vehicle population and VMT offsets the benefits of further fleet fuel economy improvements.

Figure 11. Baseline GHG and NOx Emissions in Study Area, 2016 – 2040



The table below shows further summary information on the baseline emission in the study area – vehicle population, NOx emissions, and GHG emissions by the three vehicle types for 2016 and 2040. Looking at contributions by vehicle type, light duty vehicles dominate the vehicle population at 96 percent of all vehicles. Yet LDVs produce only 38 percent of NOx emission currently, declining to 17 percent in 2040. In contrast, heavy duty vehicles account for only 2 percent of the population but produce half of all on-road NOx emissions, rising to 71 percent in 2040. This is because, per vehicle, HDVs drive more and emit a much higher rate of NOx emissions per mile. In general, NOx emissions are much higher from diesel engines than gasoline engines, and nearly all HDVs are diesel.

In terms of GHG emissions, LDVs produce the bulk of on-road vehicle emissions – 81 percent currently and 77 percent in the future. HDVs produce 15 percent of on-road GHGs currently, rising to 18 percent in 2040. Thus, HDVs (and MDVs) account for a disproportionate share of GHG emissions because, per vehicle, they drive more and burn more fuel per miles than LDVs. But the differences are not as stark as with NOx emissions.

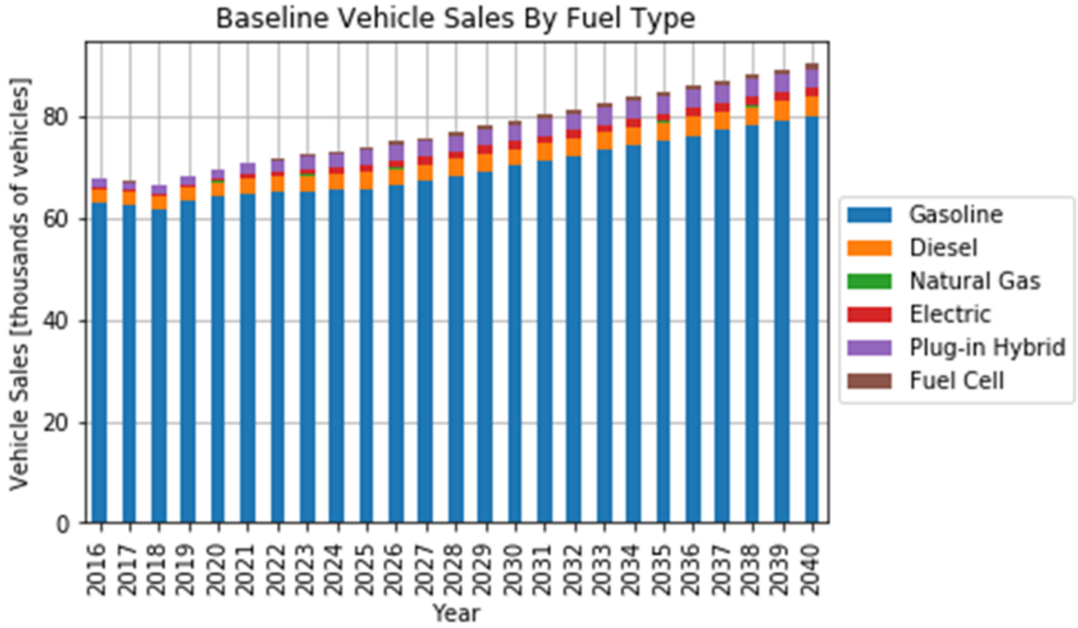
Table 14. Summary of Vehicle Population and Emissions, 2016 and 2040

	2016		2040	
	Vehicle Population (thousand)			
Light Duty	852.54	96%	1314.82	96%
Medium Duty	17.13	2%	25.71	2%
Heavy Duty	17.70	2%	24.01	2%
Total	887.37	100%	1364.54	100%
	NOx Emissions (thousand metric tons)			
Light Duty	3.15	38%	0.58	17%
Medium Duty	0.98	12%	0.40	12%
Heavy Duty	4.06	50%	2.37	71%
Total	8.19	100%	3.34	100%
	GHG Emissions (million metric tons)			
Light Duty	6.17	81%	4.60	77%
Medium Duty	0.31	4%	0.31	5%
Heavy Duty	1.14	15%	1.07	18%
Total	7.63	100%	5.98	100%

Vehicle Sales, Population, and VMT Details

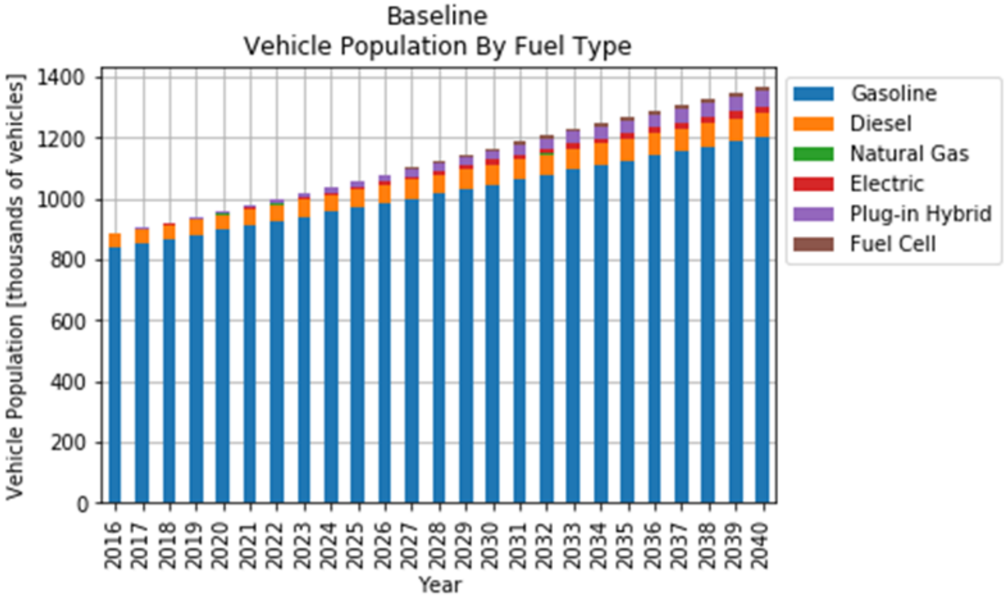
The figure below shows baseline vehicle sales by fuel type and calendar year. Gasoline vehicles dominate new vehicle sales in the study area, growing steadily from about 50,000 per year to nearly 70,000 per year in 2040. The Baseline includes only a small number of battery electric vehicles (BEVs) and plug-in hybrid electric vehicles (PHEVs). In 2040, BEVs and PHEVs account for 2 percent and 4 percent of total annual new vehicles sales in the study area, respectively.

Figure 12. Baseline Vehicle Sales by Fuel Type



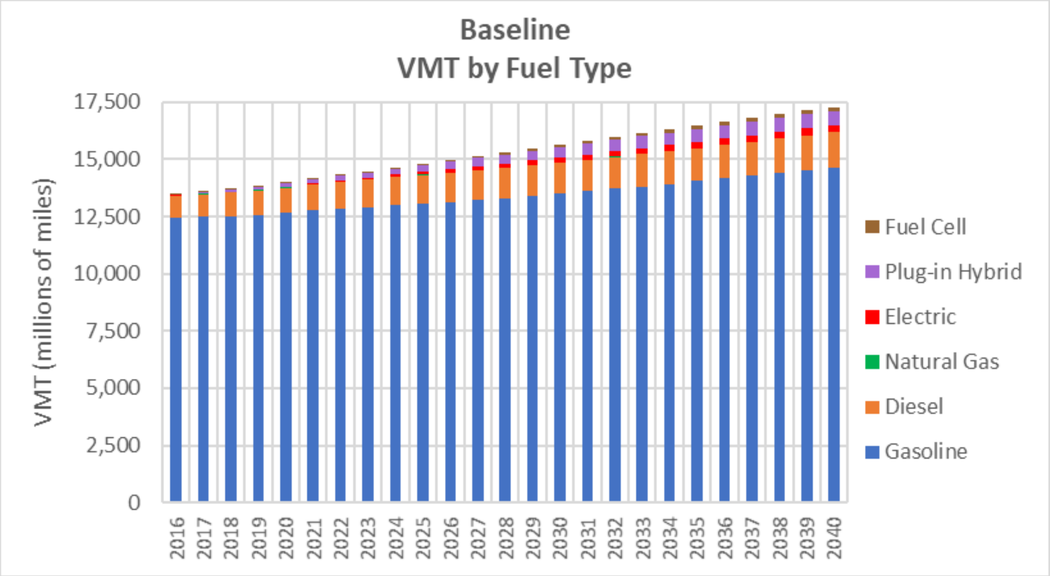
Like vehicle sales, the vehicle population is dominated by gasoline powered LDVs, which exceed 800,000 units in 2016; MDVs and HDVs comprise a relatively small portion of the vehicle population. Diesel vehicles of all classes remain the second largest category throughout the analysis period. When combined, battery electric and plug-in hybrid vehicles surpass 70,000 units in 2040 but comprise only 6 percent of the total vehicle fleet. Natural gas vehicles and FCVs make minor gains but remain a small percentage of the fleet.

Figure 13. Baseline Vehicle Population by Fuel Type



As shown in the figure below, the Baseline VMT follows a trend similar to vehicle population, rising gradually to nearly 17.5 billion VMT in 2040. Gasoline vehicles account for 93 percent of study area VMT in 2016 and 85 percent by 2040. Because heavy-duty vehicles (primarily diesel) are driven more per year than light-duty vehicles, the diesel VMT accounts for a larger fraction of VMT as compared to vehicle population. Electric, plug-in hybrid, and fuel cell vehicles account for 6 percent of all study area VMT in 2040.

Figure 14. Baseline VMT by Fuel Type

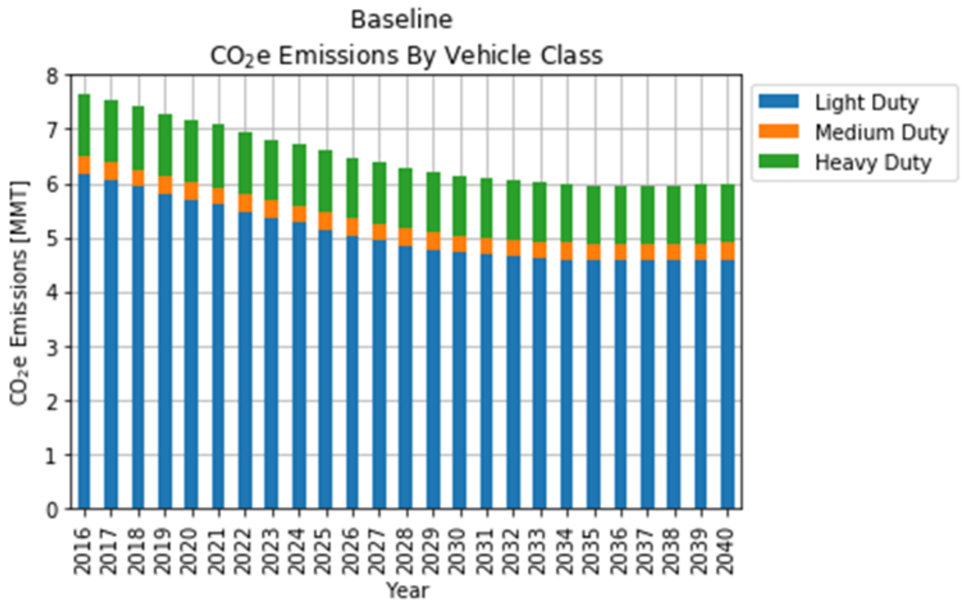


Emissions

GHG Emissions

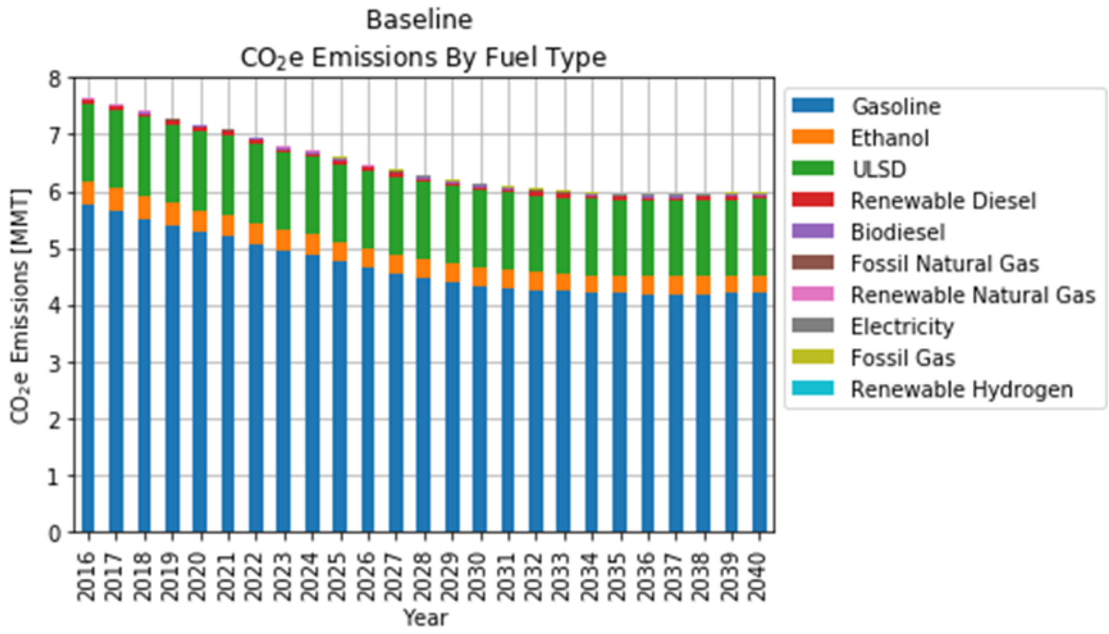
Baseline GHG emissions by vehicle class are illustrated in the figure below. Total study area on-road vehicle GHG emissions are 7.7 MMT in 2016 and decline gradually to 6 MMT in 2040 – a 22 percent decrease primarily driven by reductions in LDV emissions. LDVs comprise the greatest share of GHG emissions, representing approximately 75-80 percent of annual emissions annually throughout the analysis period. The heavy-duty sector experiences only slight emissions reductions between 2016 and 2040, indicating the difficulty of decarbonizing HDVs under current policies and with business-as-usual technologies.

Figure 15. Baseline GHG Emissions by Vehicle Type



The figure below illustrates baseline GHG emissions by vehicle fuel type. Combustion of gasoline fuel, used in LDVs and some MDVs, represents 70-75 percent of on-road GHG emissions on an annual basis throughout the analysis period. Diesel, primarily used by HDVs, generates approximately 20 percent of GHG emissions annually. Emissions from other fuels – ethanol, renewable diesel, biodiesel, fossil natural gas, renewable natural gas, electricity, fossil gas, and renewable hydrogen – make up a minor percentage of emissions. They also generally produce less emissions per unit of energy than gasoline and diesel fuels and are consumed at lower volumes.

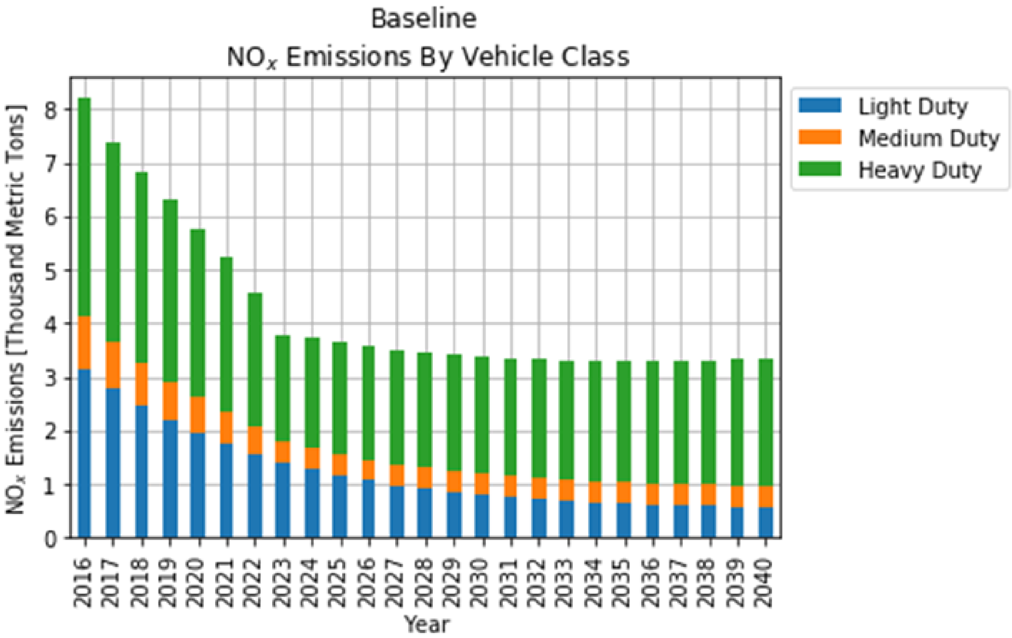
Figure 16. Baseline GHG Emissions by Vehicle Fuel Type



Nitrogen Oxide Emissions

The figure below shows NOx emissions by vehicle class in the Baseline Scenario. Overall, on-road NOx emissions experience a much more significant decrease than GHG emissions under the Baseline Scenario – declining by over 50 percent between 2016 and 2040. In contrast to GHG emission sources, NOx emissions from the on-road transportation sector are primarily driven by HDVs. Although all vehicle classes produce less NOx emissions in 2040 than in 2016, HDVs emissions reach their lowest level in 2023 and gradually increase through the remainder of the analysis period. This rebound in emissions is driven by the conclusion of CARB's Truck and Bus Rule in 2023 and the growth of VMT through 2040.[185] Moreover, the HDV share of NOx emissions increases from 60 percent in 2016 to over 80 percent in 2040 – indicating that the greatest opportunity for significant NOx reductions beyond the baseline scenario lies in the heavy-duty sector.

Figure 17. Baseline NOx Emissions by Vehicle Type



Breaking out NOx emissions by fuel type illustrates that diesel vehicles are the dominant contributor to NOx pollution given its use in the heavy-duty sector. Gasoline vehicles comprises 31 percent of annual NOx emissions in 2016 but declines to 16 percent in 2040. Other fuels contribute negligibly to NOx emissions throughout the analysis period; BEVs and FCVs produce zero NOx emissions.

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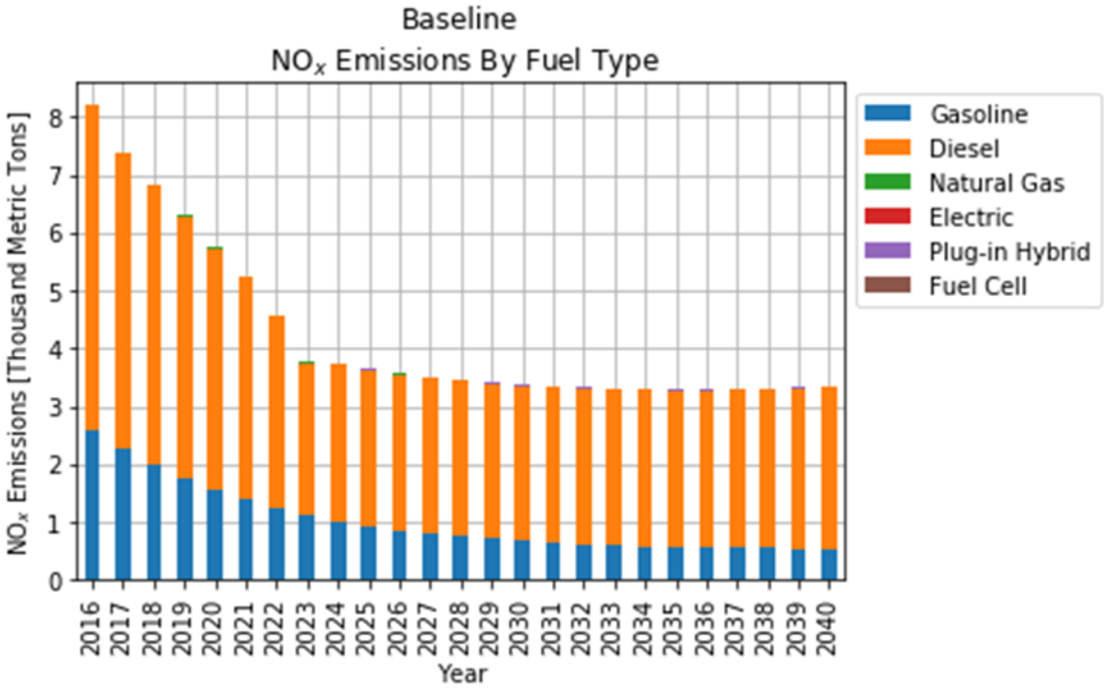
[185] https://ww2.arb.ca.gov/our-work/programs/truck-and-bus-regulation

Figure 18. Baseline NOx Emissions by Vehicle Fuel Type



Costs

To characterize the costs of each scenario, we calculate four types of costs:

- Vehicle purchase costs
- Fueling costs
- Fueling infrastructure costs
- Vehicle maintenance costs

The analysis tool calculates costs based on the estimated vehicle sales and VMT in a given year. Total vehicle purchase costs are estimated by applying the per-vehicle price assumptions (described above) to the vehicle sales in each analysis year. Total fueling costs are estimated by applying the unit fuel price assumptions (described above) to the vehicle fuel consumption in each analysis year. To estimate total fueling infrastructure costs, the analysis tool determines the number of fueling stations/chargers necessary to serve the vehicle population in each year; if any additional stations/chargers are needed, we assume they are constructed at a cost equal to the assumptions outlined above. Total maintenance costs are estimated by applying the per-mile cost assumptions to the VMT by vehicle type.

These costs, expressed in 2019 US dollars, can fall on different entities. Vehicle purchase costs are borne by vehicle owners – primarily households in the case of LDVs and commercial fleet owners in the case of MDVs and HDVs. Fueling costs are also borne primarily by the vehicle owner and operator. Fueling infrastructure costs are borne primarily by the commercial providers of gasoline, diesel, natural gas, and biofuels. In some cases, public sector entities may support fueling infrastructure development for alternative fuels. For electric vehicles, the costs of charging infrastructure are borne by homeowners (home charging equipment), private charging infrastructure providers, and in some cases, government entities that install public charging infrastructure. Vehicle maintenance costs are borne by the vehicle owner and operator.

Vehicle Purchase Costs

The analysis calculates aggregate vehicle purchase costs, which reflect the total expenditures on new vehicle purchasing in the study area by year. Under the Baseline Scenario, these vehicle purchase costs reflect the expenditures for new vehicles as part of normally fleet turnover. The Baseline aggregate vehicle purchase costs can be compared to costs under the other scenarios (discussed in Section 5) to show how accelerated purchasing of cleaner vehicles (e.g., gasoline or natural gas vehicles) will affect total expenditures on new vehicles.

Under the Baseline Scenario, total annual vehicle purchase costs increase from $2 billion in 2016 to $2.9 billion in 2040. Because LDVs account for the vast majority of new vehicle sales in the study area, they account for approximately 93 percent of annual vehicle purchase costs throughout the analysis period. The three figures below show Baseline Scenario vehicle purchase costs for LDVs, MDVs, and HDVs. Gasoline vehicles also make up 80-90 percent of vehicle purchase costs annually throughout the analysis period. In aggregate, PHEV, BEV, and FCV costs increase to nearly 7 percent of total by 2040. Diesel vehicles comprise approximately 12 percent of MDV vehicle purchase costs. HDV costs are driven almost exclusively by diesel vehicles, with natural gas vehicles contributing approximately 6 percent to total HDV costs.

Figure 19. Baseline Light Duty Vehicle Purchase Costs

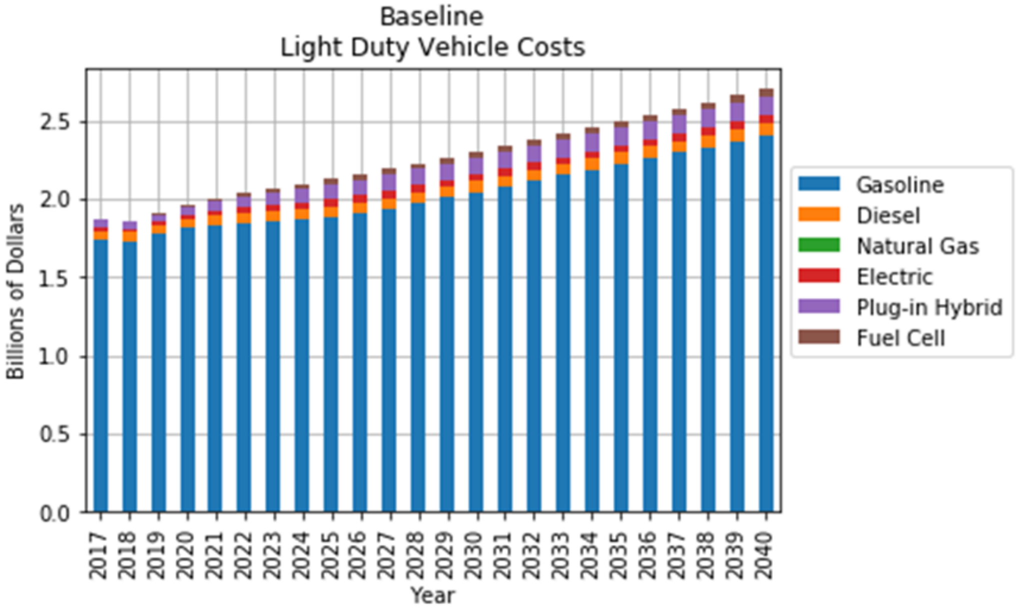


Figure 20. Baseline Medium Duty Vehicle Purchase Costs

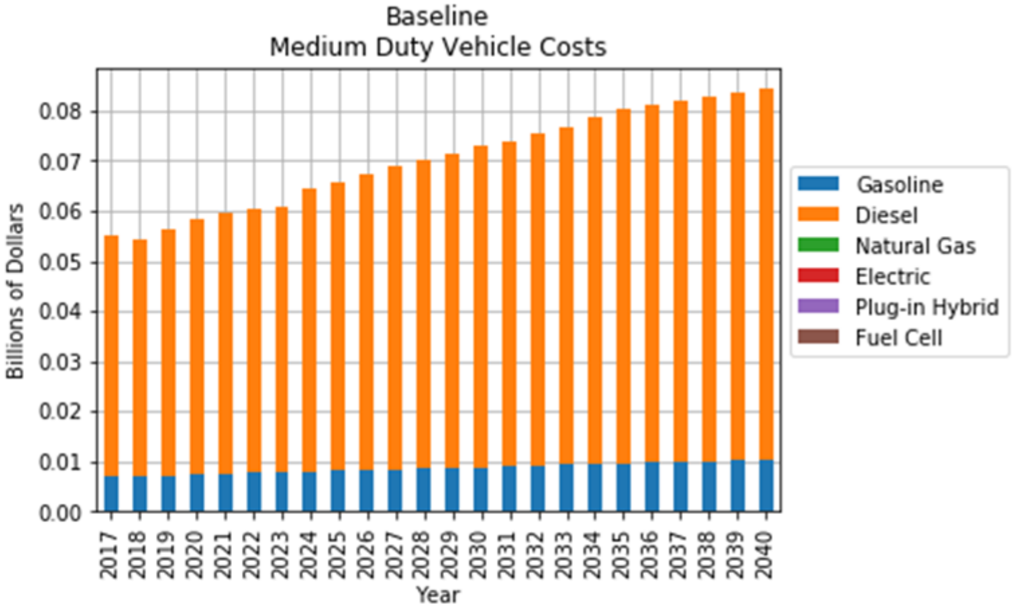
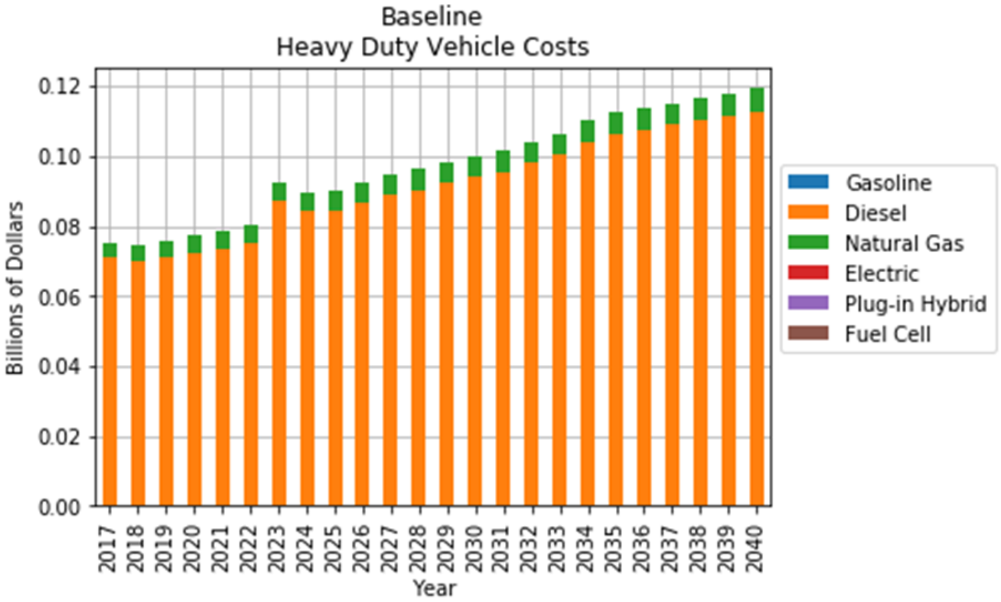


Figure 21. Baseline Heavy Duty Vehicle Purchase Costs



Fueling Costs

As illustrated in the figures below, fuel costs are generally commensurate with the composition of the vehicle population (e.g. gasoline, electric, etc.). Gasoline is the major cost driver for LDVs while diesel is the major cost driver for MDVs and HDVs. Low per-unit electricity costs make electricity's contribution overall fuel costs *de minimis.*

Figure 22. Baseline Light Duty Vehicle Fueling Costs

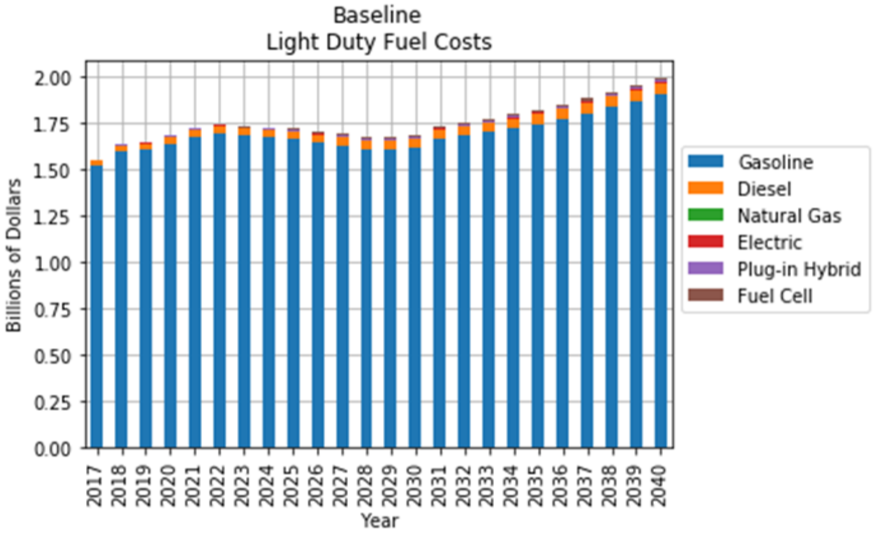


Figure 23. Baseline Medium Duty Vehicle Fueling Costs

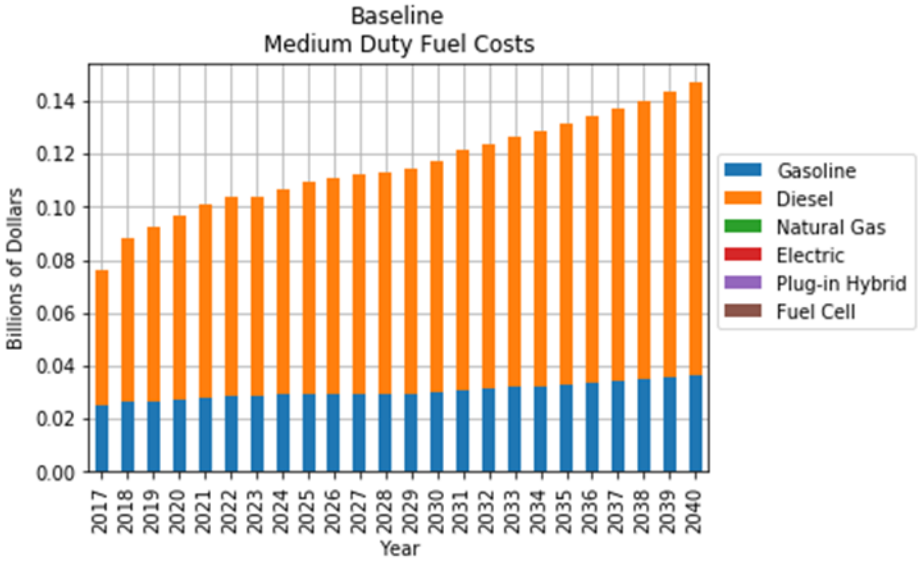
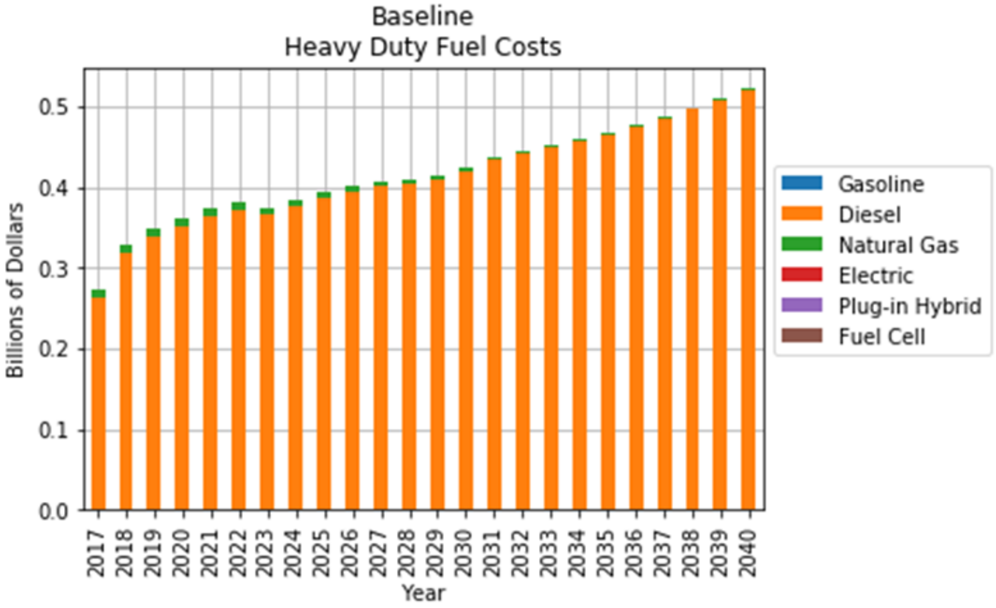


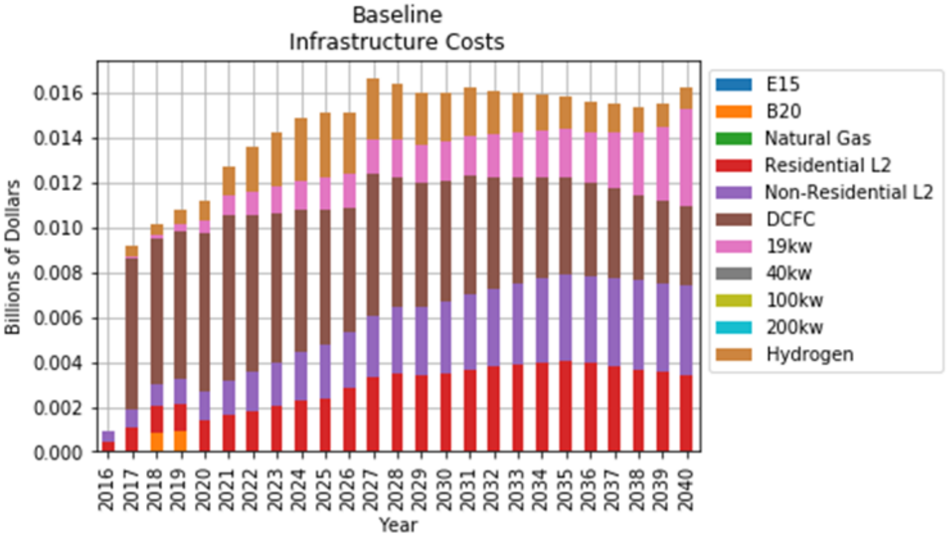
Figure 24. Baseline Heavy Duty Vehicle Fueling Costs



Fueling Infrastructure Costs

Baseline infrastructure costs in the figure below are relatively minor relative to other transportation cost categories and do not exceed $200 million in any given year in the analysis period. These costs are primarily driven by light-duty BEV charging infrastructure. Medium-duty infrastructure is driven by 19 kW chargers while Heavy-duty infrastructure is driven by biodiesel fueling investments. These costs are relatively small because the number of alternative fuel vehicles in the Baseline Scenario is modest.

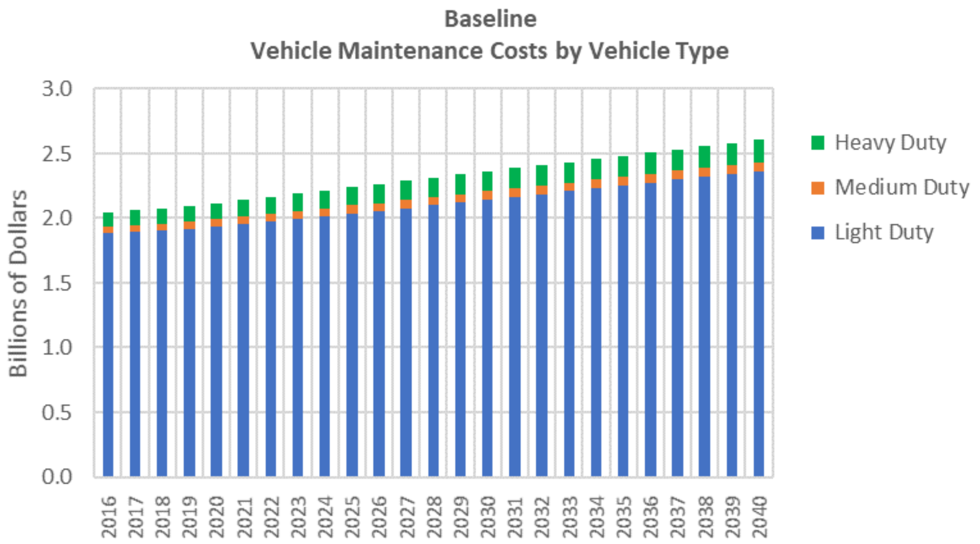
Figure 25. Baseline Fueling Infrastructure Costs



Maintenance Costs

Baseline vehicle maintenance costs rise in step with VMT, growing from $2 billion in 2016 to $2.6 billion in 2040. Maintenance costs are driven primarily by LDVs. As described in Section 4.1, a gasoline powered light duty automobile is assumed to have a per-mile maintenance cost of $0.14 versus $0.19 for typical diesel medium and heavy duty vehicles. However, because LDVs account for the vast majority of VMT, they dominate total maintenance costs even though their per-mile cost is lower. The figure below shows aggregate vehicle maintenance costs by vehicle type. LDVs around for 91 percent of total maintenance costs.

Figure 26. Baseline Vehicle Maintenance Costs



The table below shows the cumulative costs over the full analysis period. The three major cost components – vehicle purchase costs, fueling costs, and maintenance costs – are all similar in magnitude, roughly $60 billion over the full 24-year analysis period. Fueling infrastructure costs are much lower in the Baseline Scenario. This is because the scenario involves relatively few alternative fuel vehicles, and the existing fueling infrastructure for gasoline and diesel is adequate to serve the vast majority of vehicles under the Baseline Scenario.

Table 15. Baseline Scenario Cumulative Costs, 2016 – 2040

Cost Category	2016 - 2040 Cumulative Cost (billion)
Vehicle Purchase Costs	60.3
Fueling Costs	56.8
Fueling Infrastructure Costs	0.4
Vehicle Maintenance Costs	57.9

4.3 Scenario Development Process

We developed four scenarios that represent alternative paths to addressing air quality and climate changes goals in San Bernardino County. To illustrate the trade-offs among the path options, these scenarios are defined to focus heavily on a single fuel type or technology. In brief, the scenarios are:

- **Electrification.** This scenario reflects a future with a faster-than-expected transition towards electrification among all vehicle types.
- **Natural Gas as a Bridge to Electrification.** This scenario relies primarily on natural gas (renewable) for heavy-duty vehicle emission reductions through the South Coast Air Basin ozone attainment period (early 2030s). NGVs essentially serve as a bridge technology until electric truck costs decline sufficiently to warrant significant deployment in medium and heavy duty sectors. For LDVs, the scenario assumes electrification.
- **Liquid Biofuels.** This scenario reflects a future with aggressive reductions across the spectrum linked to liquid biofuel consumption—including reduced carbon intensity of existing ethanol, higher consumption of ethanol in light-duty vehicles, and renewable diesel in heavy-duty vehicles. Accelerated turnover of the vehicle fleet is not needed.
- **Biofuels and Low NOx Diesel Engines.** This scenario reflects a future with low NOx diesel engines for heavy duty trucks in addition to the potential reductions linked to liquid biofuel consumption. Accelerated turnover of the vehicle fleet is not needed.

Each scenario is described in greater detail below.

Electrification Scenario

The Electrification Scenario assumes that sales of battery electric vehicles increase rapidly as compared to the Baseline. The assumed timing and rate of EV deployment varies by vehicle type. Electrification occurs most rapidly among the smaller light duty vehicles, reflecting the current commercial offerings and expected potential for market penetration. By 2040, this scenario assumes 80 percent of new sales of these autos and light duty trucks are EVs. For the larger and heavier light duty vehicles (EMFAC categories MDV and LHD1, or GVW 6,000 to 10,000 lbs.), we assume slower introduction of EVs, ramping up to 15 percent in 2030 and 50 percent by 2040.

For MD and HD vehicles, EV sales through 2030 are based on CARB's proposed Advanced Clean Trucks Regulation. The table below shows the sales percentage requirements for this proposed regulation.

Table 16. Zero Emission Sales Requirements for Proposed Advanced Clean Trucks Regulation

Model Year	Class 2B-3*	Class 4-8 Vocational	Class 7-8 Tractors
2024	3%	7%	0%
2025	5%	9%	0%
2026	7%	11%	0%
2027	9%	13%	9%
2028	11%	24%	11%
2029	13%	37%	13%
2030	15%	50%	15%

For the years 2031-2040, the scenario assumes a continued increase in the EV new sales fraction, reaching 75 percent for Class 4-8 vocational trucks and 35-50 percent for other medium and heavy duty trucks. The table below summarizes the EV sales fractions for this scenario. No EV sales are assumed for out-of-state trucks, since these vehicles are unlikely to be eligible for state and local incentives and may not be subject to state or local regulations. As discussed in Section 4.1, because EMFAC breaks out the VMT and emissions associated with out-of-state vehicles, the analysis can treat these vehicles differently that in-state vehicles.

Table 17. EV Sales Fractions by Vehicle Type – Electrification Scenario

Vehicle Type	FHWA Class	2030	2040
Light Duty	1	41.5%	80%
Light Duty	2	15%	50%
Medium Duty	3	15%	50%
Medium Duty	4	50%	75%
Medium Duty	5	50%	75%
Medium Duty	6 (IRP and Ag)	15%	50%
Medium Duty	6 (out of state)	0%	0%
Medium Duty	6 (all other)	50%	75%
Heavy Duty	7 (IRP)	15%	35%
Heavy Duty	7 (out of state)	0%	0%
Heavy Duty	7 (all other)	50%	75%
Heavy Duty	8 (vocational)	50%	75%
Heavy Duty	8 (tractors)	15%	35%
Heavy Duty	8 (out of state)	0%	0%

Note: IRP is International Registration Plan

Natural Gas as a Bridge to Electrification Scenario

The Natural Gas as a Bridge to Electrification Scenario assumes rapid acceleration of natural gas vehicles (NGV) among most medium and heavy duty vehicle types through 2030. Natural gas engines are currently available for these vehicles and are used in select applications. By 2030, this scenario assumes that NGVs account for 40 percent to 45 percent of new sales for most medium and heavy duty truck types. After 2030, the sales fraction for NGVs begins to decline, on the assumption that EVs will become more cost effective for these vehicle types after 2030.

For small light duty vehicles (autos and light trucks), this scenario assumes new sales of EVs will be identical to the Electrification Scenario. This assumption is a reflection of the minimal interest among manufacturers and consumers for light duty NGVs.

In this scenario, all new NGVs are assumed to use renewable natural gas, which produces significantly lower GHG emissions than conventional (fossil) natural gas. As with the Electrification Scenario, no NGV or EV sales are assumed for out-of-state trucks, since these vehicles are unlikely to be eligible for state and local incentives and may not be subject to state or local regulations. The table below summarizes the NGV and EV sales fractions for this scenario.

Table 18. NGV and EV Sales Fractions by Vehicle Type – Natural Gas as a Bridge Scenario

Vehicle Type	FHWA Class	Natural Gas		Electric	
		2030	2040	2030	2040
Light Duty	1	0%	0%	41.5%	80%
Light Duty	2	10%	10%	5%	25%
Medium Duty	3	10%	10%	5%	25%
Medium Duty	4	25%	25%	5%	50%
Medium Duty	5	45%	35%	5%	35%
Medium Duty	6 (IRP and Ag)	40%	20%	5%	25%
Medium Duty	6 (out of state)	0%	0%	0%	0%
Medium Duty	6 (all other)	45%	35%	5%	35%
Heavy Duty	7 (IRP)	40%	20%	5%	25%
Heavy Duty	7 (out of state)	0%	0%	0%	0%
Heavy Duty	7 (all other)	45%	35%	5%	35%
Heavy Duty	8 (vocational)	45%	35%	5%	35%
Heavy Duty	8 (tractors)	40%	20%	5%	25%
Heavy Duty	8 (out of state)	0%	0%	0%	0%

Liquid Biofuels Scenario

The Liquid Biofuels Scenario assumes significant increases in the use of biofuels (ethanol, biodiesel, renewable diesel) among all vehicle types as well as reductions in the carbon intensity of biofuels. Both changes result in reduced GHG emissions as compared to conventional gasoline and diesel vehicles, but does not affect NOx emissions. Because most biofuels can be blended with conventional gasoline or diesel and these blends can be used in conventional internal combustion engines, this scenario does not require accelerated turnover of the vehicle fleet.

This scenario assumes the ethanol blend in gasoline increases to 15 percent by 2040. Today, reformulated gasoline (RFG) contains 10 percent ethanol by volume – and RFG makes up more than 95 percent of the gasoline fuel market in the United States. This is largely driven by the federal Renewable Fuel Standard, which is a supply-side driver for ethanol production. Higher ethanol blends are currently limited by infrastructure and vehicle warranty concerns. The U.S. EPA has approved for use 15 percent ethanol blends (E15) in model year 2001 and newer light-duty conventional gas vehicles. However, some in the automotive industry contend that the use of E15 has the potential to accelerate wear and tear and ultimately lead to vehicle failure. There are also significant concerns about consumer education and outreach regarding the appropriate use of E15, and some fuel retailers are concerned about impacts on infrastructure. All of these concerns could be addressed and result in an increase in ethanol blending.

The scenario also assumes that the carbon intensity of ethanol will decline 35 percent by 2035. On a life cycle basis, ethanol produced from corn reduces GHG emissions by about 30 percent, and the Baseline Scenario assume this corn-based ethanol will continue to be used, as discussed in Section 4.2. Ethanol produced with cellulosic feedstocks can reduce lifecycle GHG emissions from 50 to 90 percent. Ethanol producers are seeking to reduce their carbon intensity, and the carbon intensity of ethanol has decreased steadily over time. Older facilities with high carbon intensity were nearly phased out by the end of 2017, with ethanol with carbon intensity higher than 75 g/MJ decreasing from nearly 90 percent of the ethanol LCFS credits in 2011 to less than 5 percent in 2018. With a 35 percent reduction, the carbon intensity of ethanol would be 44.6 g CO2e/MJ in 2035.

For medium and heavy duty diesel vehicles, this scenario assumes an increase in the biodiesel blend from 5 percent in the Baseline Scenario to 10 percent by 2040. As described in Section 3, biodiesel is a fatty acid methyl ester (FAME) that can be synthesized from vegetable oils, waste oils, fats, and grease. Biodiesel is generally used in low-level blends: biodiesel blended in at 5 percent by volume is considered the same as diesel, and biodiesel blended at 20 percent by volume is the upper limit of blending for the majority of transportation applications due to vehicle warranty. In California, the LCFS is driving increased use of biodiesel. However, CARB’s Alternative Diesel Fuel (ADF) Rulemaking will limit the potential for biodiesel blending in the near-term future because of concerns about biodiesel blends to increase NOx emissions. These concerns are expected to wane as older diesel vehicles are retired.

The scenario assumes the carbon intensity of biodiesel will decline to 20 g CO2e/MJ by 2030, down from the Baseline Scenario assumption of 31.05 g/MJ. Lower carbon biodiesel can be obtained from feedstocks such as corn oil, animal fats, and cooking oil. As with ethanol, lower carbon biodiesel is being driven by the LCFS.

Lastly, this scenario assumes an increase in the renewable diesel blend to 60 percent by 2040, up from the Baseline assumption of 10 percent blend. Renewable diesel is produced via biomass-to-liquid processing. In terms of chemical and physical properties, renewable diesel meets all the requirements of ASTM D975, and is therefore considered a “drop-in” fuel. For instance, Neste Oil’s NExBTL product meets the fuel quality specifications of CARB diesel, meaning no modifications are needed to existing storage and transport infrastructure. There are current five plants producing renewable diesel – the Diamond Green facility in Louisiana and four international facilities operated by Neste, including one in Singapore that serves the California market. No change in renewable diesel carbon intensity is assumed for this scenario.

The table below summarizes the assumed changes in blend percentages and carbon intensity for the Biofuels Scenario.

Table 19. Changes in Blend Percentages and Carbon Intensity – Biofuels Scenario

Fuel	Blend Percentage		Carbon Intensity (g CO2e/MJ)	
	Baseline	Scenario (2040)	Baseline	Scenario (2040)
Ethanol	10%	15%	68.6	44.6
Biodiesel	5%	10%	31.05	20.0
Renewable Diesel	10%	60%	32.17	32.17

Biofuels and Low NOx Diesel Engines Scenario

This scenario includes all the assumptions of the Biofuels Scenario plus an increase in deployment of diesel engines that produce lower NOx emissions. This scenario can therefore achieve reductions in both GHG emissions and NOx emissions compared to the Baseline Scenario.

Emission standards adopted by the U.S. EPA require that new heavy duty vehicle NOx emissions do not exceed 0.2 g/bhp-hr starting with model year 2010. The Baseline Scenario assumes this standard will remain in place throughout the analysis years. Manufacturers have generally complied with this standard though the use of selective catalytic reduction (SCR) emission control systems. Since 2010, the effectiveness of emission control technologies has improved and their costs have declined. Both EPA and CARB have announced rulemakings focused on revising the heavy-duty truck NOx emission standards, targeting 2024 to 2027 for implementation. The Manufacturers of Emission Controls Association (MECA) reports that technologies are available that can be deployed on vehicles by model year 2024 to achieve 0.05 g/bhp-hr NOx standard.[186]

There is uncertainty as to whether all diesel trucks could consistently achieve a 0.05 g/bhp-hr NOx standard. This scenario assumes that new sales of diesel trucks have engines that meet a 0.1 g/bhp-hr NOx standard starting in 2025 (50% NOx reduction from current standard of 0.2 g/BHP-hr). The low-NOx technology is assumed to add $10,000 to the vehicle purchase price.

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[186] Manufacturers of Emission Controls Association, *Technology Feasibility for Model Year 2024 Heavy-Duty Diesel Vehicles in Meeting Lower NOx Standards*, June 2019.

5 Analysis Results

This section describes the results of the scenario analysis. Each scenario is discussed individually, including both emissions impacts and costs. The final subsection presents a summary of the results.

5.1 Scenario A: Electrification

The Electrification Scenario assumes a much more aggressive introduction of BEVs into the vehicle fleet than the Baseline scenario. The gasoline vehicle population reaches a peak of 931,000 vehicles in 2025 and then gradually declines to 670,000 units in 2040 as BEVs reach increasingly greater adoption levels across all vehicle classes – growing to nearly 580,000 units in 2040. In total, BEVs and PHEVs make up half the vehicle population in 2040, up from only 0.4 percent in 2016. Of the BEVs in the 2040 vehicle population, 565,000 are LDVs while the balance is comprised of approximately 9,000 MDVs and 5,000 HDVs.

Figure 27. Electrification Scenario Vehicle Population by Fuel Type

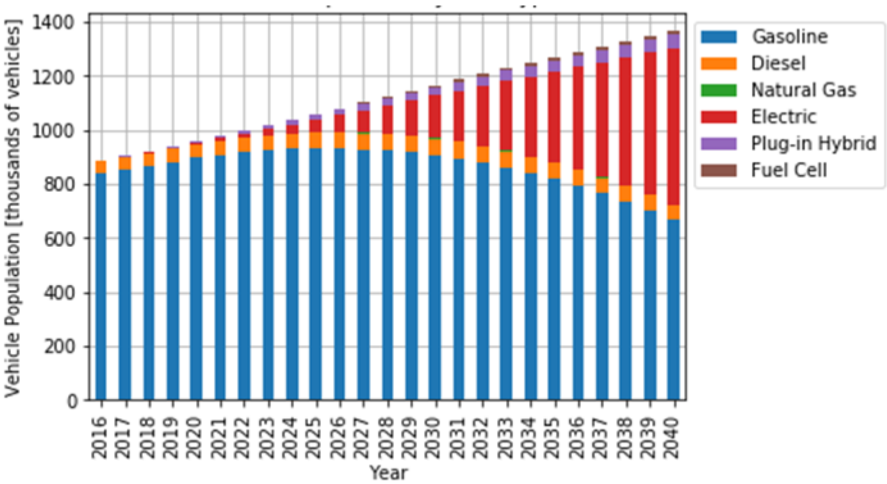


Table 20. Electrification Scenario Vehicle Population by Vehicle Type, 2016, 2030, and 2040

Type	Fuel	2016		2030		2040	
		Vehicles (000)	Percent	Vehicles (000)	Percent	Vehicles (000)	Percent
LDV	Gasoline	836.5	98%	902.4	81%	666.5	51%
	Electric	0.9	0%	155.9	14%	565.2	43%
	Plug-in Hybrid	1.0	0%	31.0	3%	48.9	4%
	Other	14.2	2%	30.5	3%	34.3	3%
	Sub-Total	**852.5**	**100%**	**1119.8**	**100%**	**1314.8**	**100%**
MDV	Gasoline	4.3	25%	3.9	17%	3.2	12%
	Diesel	12.8	75%	17.2	76%	13.7	53%
	Electric	0.0	0%	1.6	7%	8.8	34%
	Sub-Total	**17.1**	**100%**	**22.6**	**100%**	**25.7**	**100%**

HDV	Diesel	16.8	95%	20.7	91%	18.2	76%
	Electric	0.0	0%	0.8	4%	5.0	21%
	Other	0.9	5%	1.2	5%	0.8	3%
	Sub-Total	**17.7**	**100%**	**22.7**	**100%**	**24.0**	**100%**

Emissions Impacts

As shown in the figure and table below, GHG emissions in the Electrification scenario decline to 3.7 million metric tons (MMT) in 2040, resulting in a 37 percent reduction relative to Baseline emissions in 2040. These reductions are driven by the introduction of BEVs: despite their relatively high penetrations in the second half of the analysis period, BEVs contribute marginally to GHG emissions given their fuel efficiency and the low emissions of their fuel source – which becomes increasingly generated by renewable resources as the scenario advances. LDVs experience the most significant GHG emission reductions – in both relative and absolute terms – suggesting that a focus on light-duty electrification can yield lower on-road sector GHG emissions in the short-, medium-, and long-term.

Figure 28. Electrification Scenario CO2e Emissions by Vehicle Type

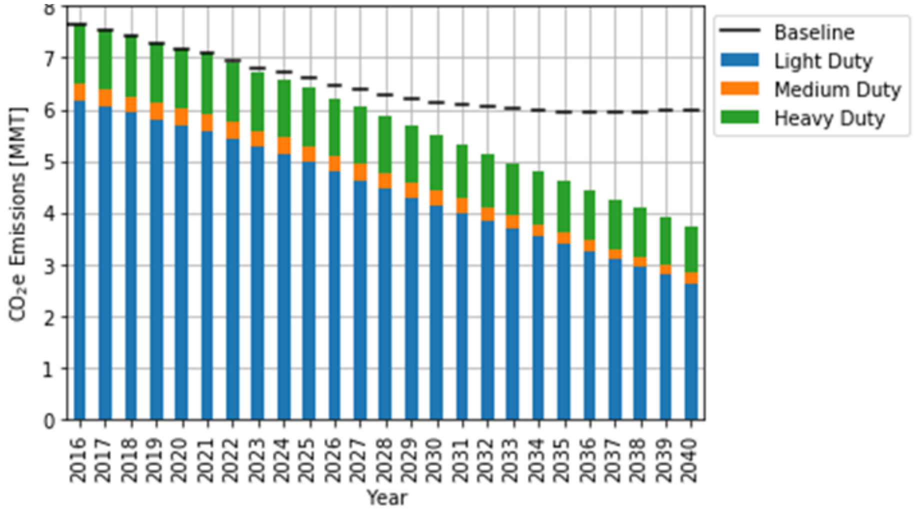


Table 21. Electrification Scenario CO2e Emissions Impacts (MMT), 2040

Vehicle Type	Baseline Scenario	Electrification Scenario	Difference
Light Duty	4.60	2.65	-42%
Medium Duty	0.31	0.19	-40%
Heavy Duty	1.07	0.91	-16%
Total	**5.98**	**3.74**	**-37%**

The figure and table below show the NOx emissions of the Electrification Scenario. As discussed in Section 4, the Baseline NOx emissions (shown with a black line in the chart) decline rapidly through 2023 due mostly to the state Truck and Bus Rule. The Electrification Scenario would reduce NOx emissions further below the baseline levels. NOx emissions are reduced to approximately 2,600 MT in 2040, representing a 21 percent decrease in NOx emissions relative to the Baseline in 2040. Similar to the GHG emissions results, the LDV sector experiences the greatest NOx emissions reductions in both relative and absolute terms from the aggressive introduction of BEVs. HDV NOx emissions remain the largest source of NOx emissions throughout the analysis period despite a 50 percent reduction between 2016 and 2040.

Figure 29. Electrification Scenario NOx Emissions by Vehicle Type

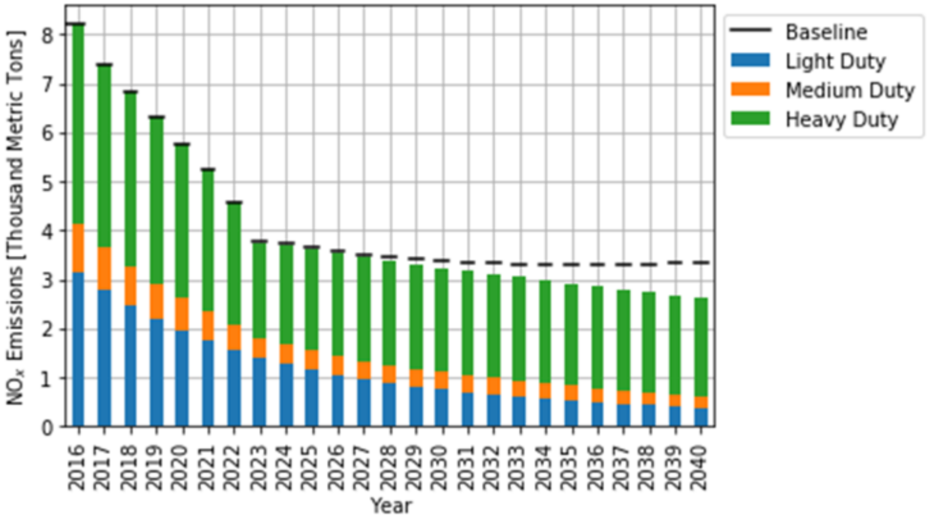


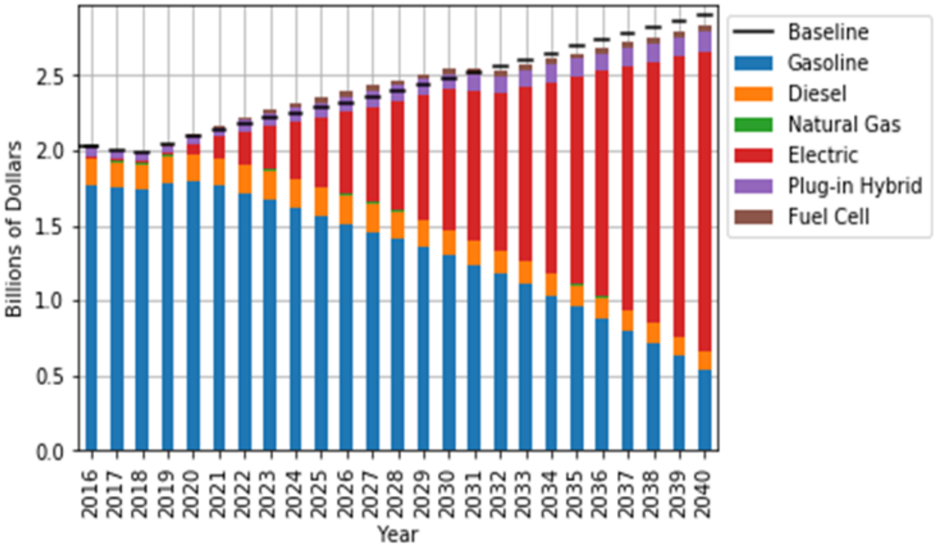
Table 22. Electrification Scenario NOx Emissions Impacts (thousand MT), 2040

Vehicle Type	Baseline Scenario	Electrification Scenario	Difference
Light Duty	0.58	0.38	-35%
Medium Duty	0.40	0.24	-41%
Heavy Duty	2.37	2.01	-15%
Total	**3.34**	**2.63**	**-21%**

Costs

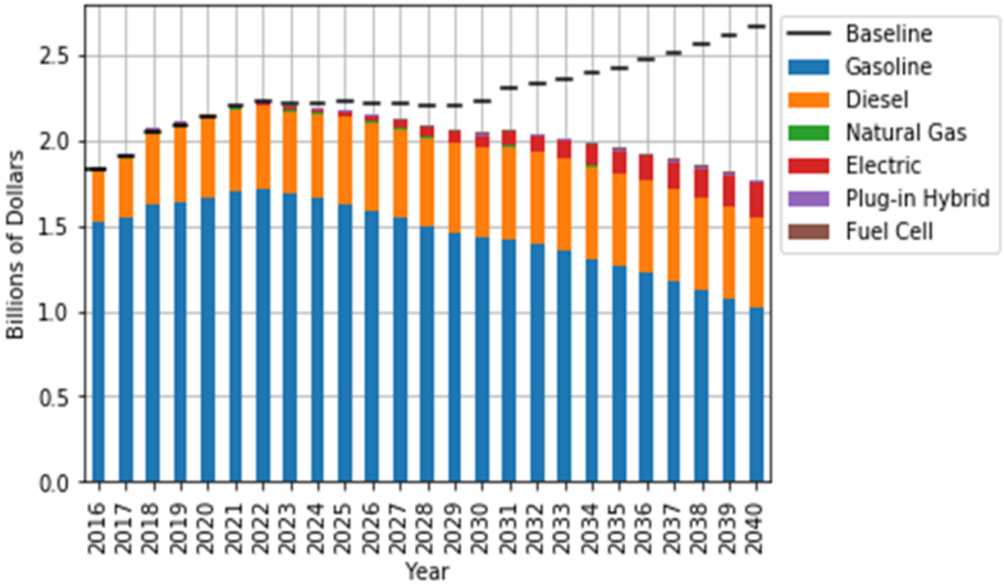
Annual vehicle purchase costs in the Electrification Scenario are similar to the Baseline Scenario, starting near $2 billion in 2016 and escalate to $2.8 billion in 2040, as shown below. BEVs become an increasingly salient cost driver as their adoption increases, comprising 71 percent of total vehicle costs in 2040. The Electrification scenario vehicle costs remain higher than the Baseline throughout the 2020s as BEV costs remain higher than many comparable petroleum vehicles. However, by the early 2030s, the annual vehicle costs cross over and become lower than the Baseline costs and end up approximately 3 percent lower than the Baseline in 2040. In other words, in 2040, total expenditures on new vehicles would be 3 percent lower under the Electrification Scenario. This is driven by the assumption that electric automobiles will have a slightly lower purchase price than gasoline vehicles starting in 2032, as described in Section 4.1.

Figure 30. Electrification Scenario Vehicle Purchase Costs



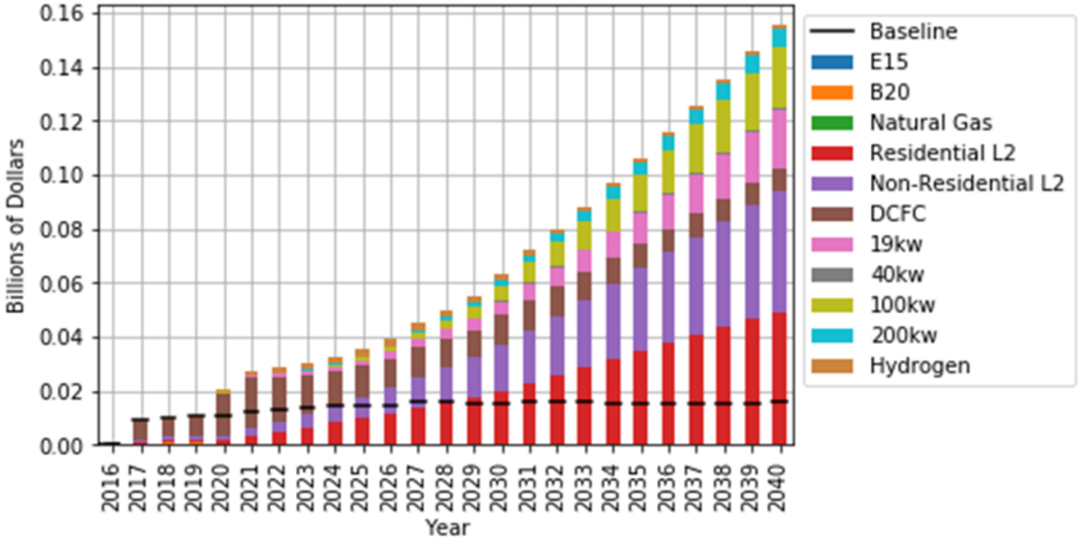
The fueling costs in the Electrification Scenario peak in 2022 at approximately $2.2 billion and decline to $1.8 billion in 2040. These reductions amount to a 34 percent reduction in annual fuel costs relative to Baseline fuel costs in 2040. Despite BEVs comprising over a third of the vehicle fleet in 2040, BEVs drive 11 percent of the fuel costs due to relatively low electric fuel prices. Annual gasoline fuel costs decrease by $500 million between 2016 and 2040 as a result of greater BEV and PHEV adoption. Diesel costs largely remain constant throughout the analysis period.

Figure 31. Electrification Scenario Fueling Costs



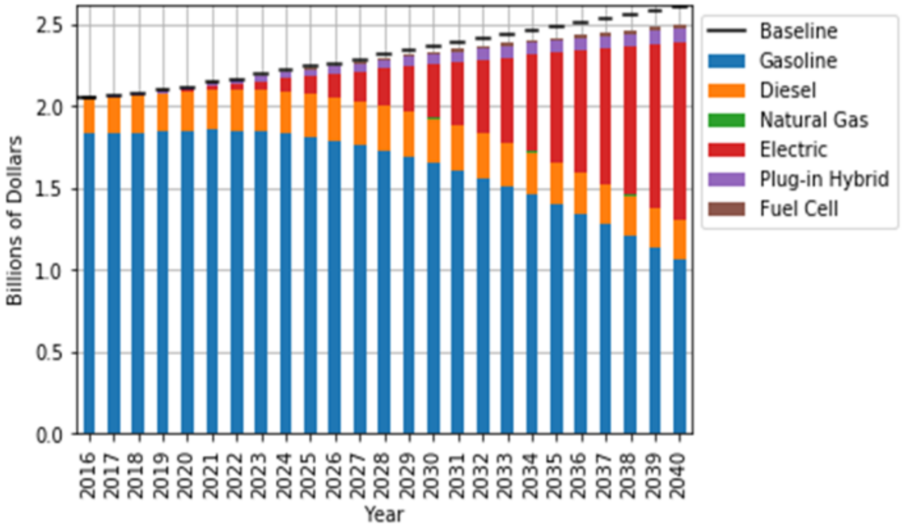
Infrastructure costs, while low relative to other transportation-related costs, are significantly higher in the Electrification Scenario than the Baseline scenario and rise to nearly $160 million in annual investment in 2040. The majority of these costs are driven by the deployment of L2 charging stations to support LDVs at home, workplace, and public locations in the latter half of the analysis period. It is important to note that DCFC station costs drive the majority of infrastructure costs until the mid-2020s, suggesting that an accessible network of DCFC stations is necessary early on to support light-duty BEV adoption in a manner consistent with Electrification Scenario BEV projections. For MDV and HDV BEVs, infrastructure costs are primarily driven by 19 kW stations and 100 kW and stations. These infrastructure costs and investment decisions will be influenced by a number of related factors, including: vehicle battery range, vehicle duty cycle, and climate conditions under which vehicles operate.

Figure 32. Electrification Scenario Infrastructure Costs



Total maintenance costs in the Electrification Scenario start near $2 billion annually in 2016 and approach $2.5 billion annually in 2040, representing a modest 6 percent annual cost reduction relative to the Baseline scenario in 2040. BEV and PHEV maintenance costs increase to approximately half of total annual maintenance costs by 2040 while gasoline vehicle maintenance costs decline gradually from $1.8 billion in 2016 to $1.1 billion in 2040. Diesel maintenance costs largely remain constant throughout the analysis period. Overall, these modest total cost reductions are driven by the lower maintenance costs associated with BEVs, which do not require the same level of maintenance as comparable petroleum fuel vehicles.

Figure 33. Electrification Scenario Maintenance Costs



5.2 Scenario B: Natural Gas as a Bridge to Electrification

The Natural Gas as a Bridge to Electrification (Bridge) Scenario follows similar vehicle population trends as the Electrification Scenario – albeit with several key differences. Electrification of the light-duty fleet drives significant growth in BEVs throughout the analysis period, contributing to a total BEV population of nearly 550,000 vehicles in 2040. The transition from light-duty gasoline vehicles to BEVs causes the gasoline vehicle fleet to peak in 2025 at 930,000 units and decline to under 700,000 units by 2040. However, natural gas vehicles grow to become the second most common vehicle type among MDVs and HDVs by 2040 – comprising 22 and 24 percent of vehicles of these types by 2040. MDVs and HDVs still experience BEV growth, but it is more modest than the electrification scenario: these vehicle classes see BEV sales begin in the mid-2020s and grow to 12 percent of the MDV fleet and 8 percent of the HDV fleet in 2040.

The figure below shows the total vehicle population in the study area by fuel type. Because the accelerated penetration of natural gas vehicles is limited to MDVs and HDVs, and these two vehicle types make up only four percent of the total vehicle population, the number of natural gas vehicles (shown in green in the chart) remains small relative to the total vehicle population, which is dominated by LDVs.

Figure 34. Natural Gas as a Bridge Scenario Vehicle Population by Fuel Type

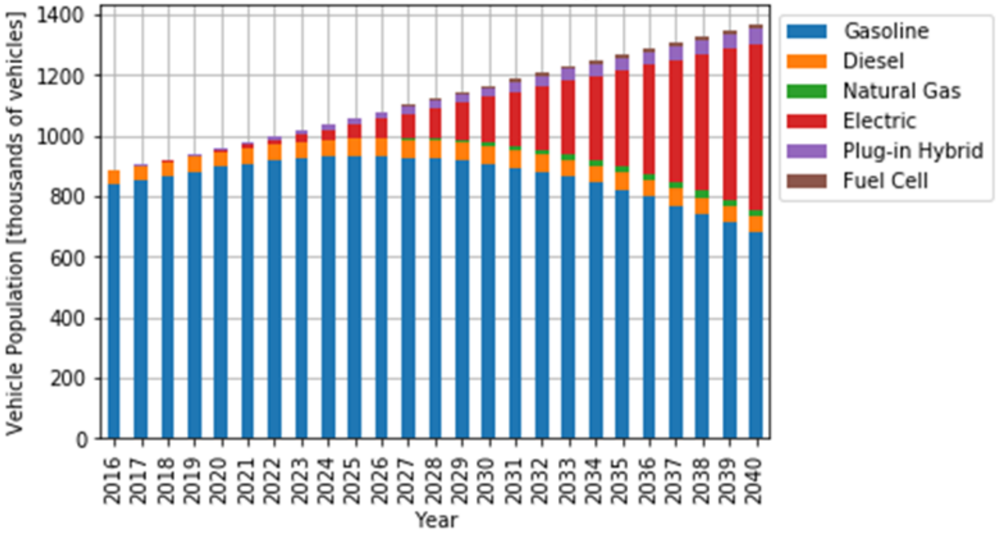
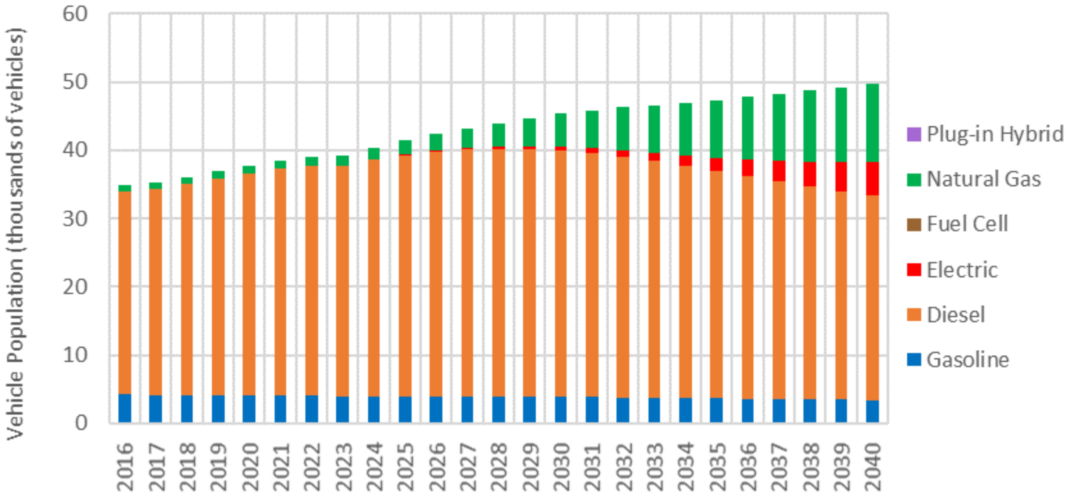


Table 23. Natural Gas as a Bridge Scenario Vehicle Population by Vehicle Type, 2016, 2030, and 2040

		2016		2030		2040	
Type	Fuel	Vehicles (000)	Percent	Vehicles (000)	Percent	Vehicles (000)	Percent
LDV	Gasoline	836.5	98%	903.2	81%	675.4	51%
	Electric	0.9	0%	151.5	14%	541.5	41%
	Plug-in Hybrid	1.0	0%	31.0	3%	48.9	4%
	Other	14.2	2%	34.1	3%	49.0	4%
	Sub-Total	**852.5**	**100%**	**1119.8**	**100%**	**1314.8**	**100%**
MDV	Gasoline	4.3	25%	3.9	17%	3.4	13%
	Diesel	12.8	75%	16.3	72%	13.6	53%
	Natural Gas	0.0	0%	2.1	9%	5.6	22%
	Electric	0.0	0%	0.3	1%	3.0	12%
	Sub-Total	**17.1**	**100%**	**22.6**	**100%**	**25.7**	**100%**
HDV	Diesel	16.8	95%	19.8	87%	16.4	68%
	Natural Gas	0.9	5%	2.7	12%	5.8	24%
	Electric	0.0	0%	0.2	1%	1.9	8%
	Other	0.0	0%	0.0	0%	0.0	0%
	Sub-Total	**17.7**	**100%**	**22.7**	**100%**	**24.0**	**100%**

The figure below shows the vehicle population by fuel type for only MDVs and HDVs. This figure illustrates the growing share of natural gas vehicles (shown in green) and, after 2030, electric vehicles (shown in red). Natural gas accounts for 23 percent of the combined MDV and HDV population in 2040, and electric vehicles account for another 10 percent.

Figure 35. Natural Gas as a Bridge Scenario Vehicle Population by Fuel Type, MDV and HDV only



Emissions Impacts

Annual GHG emissions in the Natural Gas as a Bridge Scenario decline to approximately 4 MMT in 2040, representing a 35 percent decrease in annual emissions relative to the 2040 Baseline figure. The LDV sector, the greatest contributor to GHG emissions throughout the analysis period, experiences the greatest emissions reductions in both relative and absolute terms from increased uptake of BEVs. The MDV and HDV sector experience moderate annual GHG emission reductions: 27 and 19 percent, respectively, between 2016 and 2040.

Figure 36. Natural Gas as a Bridge Scenario CO2e Emissions by Vehicle Type

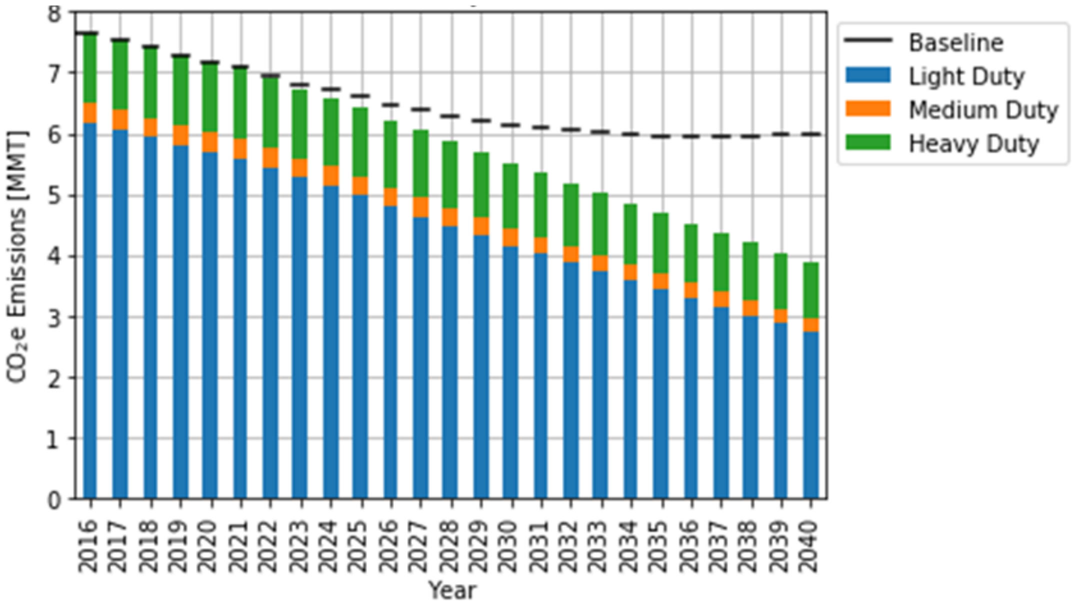


Table 24. Natural Gas as a Bridge Scenario CO2e Emissions Impacts (MMT), 2040

Vehicle Type	Baseline Scenario	Natural Gas as Bridge Scenario	Difference
Light Duty	4.60	2.73	-41%
Medium Duty	0.31	0.23	-27%
Heavy Duty	1.07	0.92	-14%
Total	**5.98**	**3.88**	**-35%**

Annual NOx emissions also experience a decline in the Bridge Scenario, falling to approximately 2,400 MT in 2040, a 27 percent decrease in annual NOx emissions relative to the 2040 Baseline figure. Despite the growth of low NOx natural gas and electric HDVs throughout the 2030s, expected increases in truck VMT keep HDV NOx emissions relatively flat during the period 2023 – 2040, although HDV NOx emissions would be 24 percent lower than the Baseline in 2040. LDVs experience significant NOx emission reductions from the transition toward BEVs and away from gasoline powered vehicles.

Figure 37. Natural Gas as a Bridge Scenario NOx Emissions by Vehicle Type

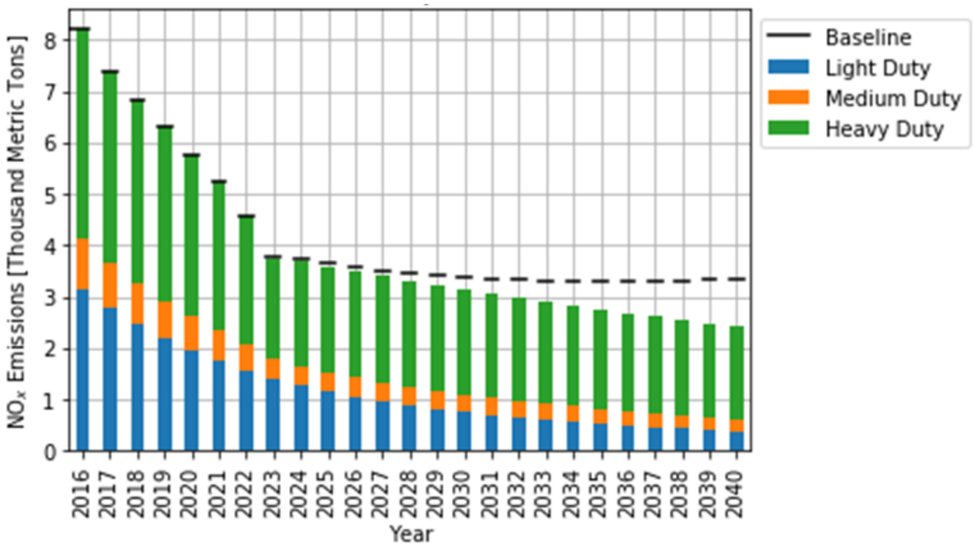


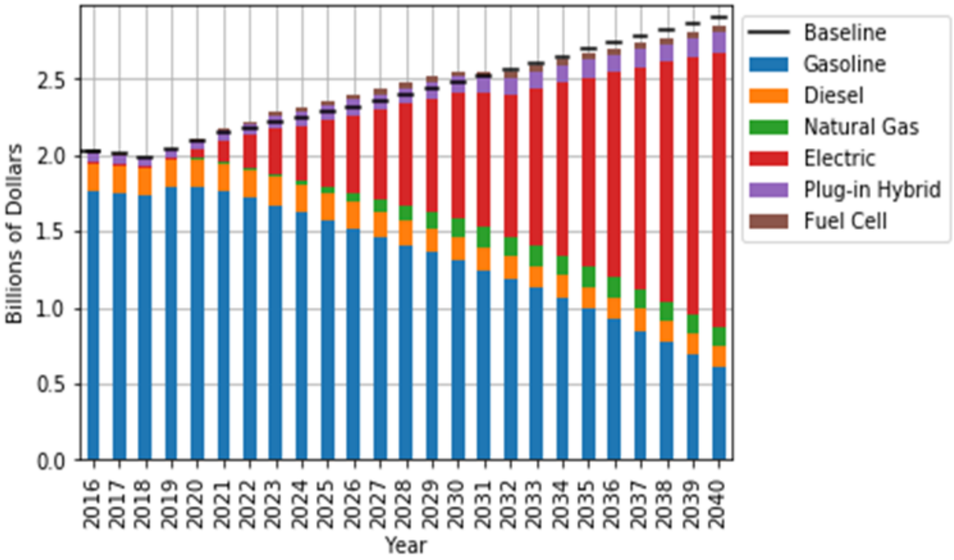
Table 25. Natural Gas as a Bridge Scenario NOx Emissions Impacts (thousand MT), 2040

Vehicle Type	Baseline Scenario	Natural Gas as Bridge Scenario	Difference
Light Duty	0.58	0.38	-34%
Medium Duty	0.40	0.24	-40%
Heavy Duty	2.37	1.81	-24%
Total	**3.34**	**2.43**	**-27%**

Costs

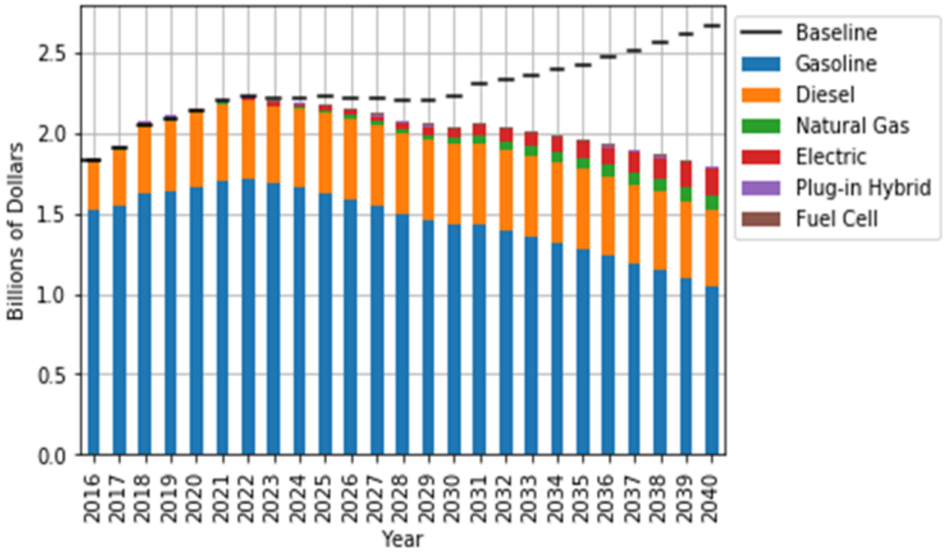
Bridge Scenario vehicle purchase costs follow a similar trend to the Electrification Scenario: BEVs become the dominant cost driver by 2040 while gasoline vehicles experience approximately $1 billion in cost declines between 2016 and 2040 due to reduced sales. Total vehicle purchase costs also exceed the Baseline Scenario estimates at the outset of the analysis period on an annual basis, based on the assumption that electric LDVs have a higher purchase price than gasoline LDVs through 2030 (as discussed in Section 4). But by 2032, electric automobiles are assumed to have a slightly lower purchase price than gasoline automobiles. Because LDVs make up the vast majority of the vehicle population, the vehicle purchase costs are driven by these differences. Purchase costs under the Bridge Scenario gradually become lower than the Baseline in the 2030s and result in marginally lower annual vehicle costs in 2040. Diesel vehicle purchase costs also decline marginally as natural gas vehicles and BEVs replace diesel vehicle sales.

Figure 38. Natural Gas as a Bridge Scenario Vehicle Purchase Costs



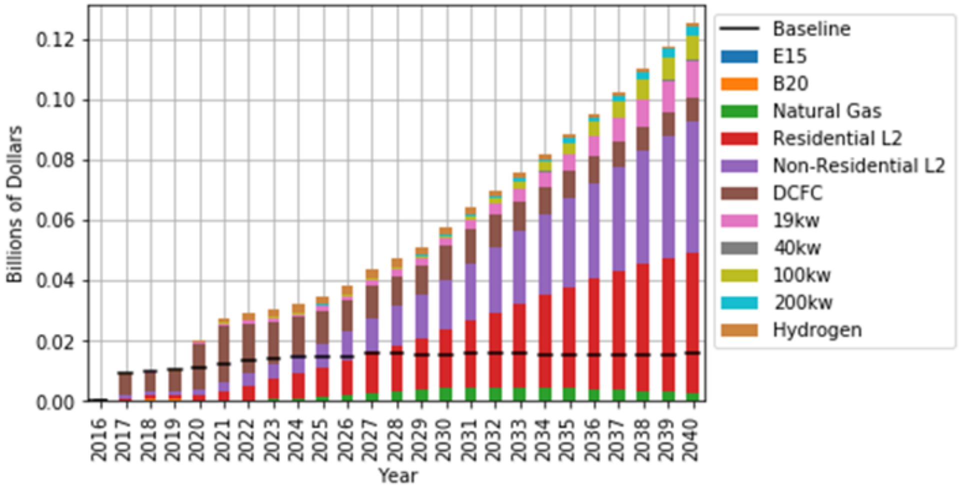
Fueling costs in the Bridge Scenario peak in 2022 at approximately $2.2 billion and gradually decline to $1.8 billion in 2040, a 34 percent decrease in annual fuel costs relative to the 2040 Baseline figure. Annual gasoline fueling costs decline by $500 million by 2040 from 2016 levels as the transition to light-duty BEVs accelerates. Natural gas comprises nearly 20 percent of MDV fueling costs and 10 percent of HDV annual fueling costs in 2040; both vehicle classes experience annual fuel cost savings relative to the Baseline scenario as natural gas vehicles and BEVs are introduced to the market. However, diesel remains the primary driver of fuel costs in these vehicle classes.

Figure 39. Natural Gas as a Bridge Scenario Fueling Costs



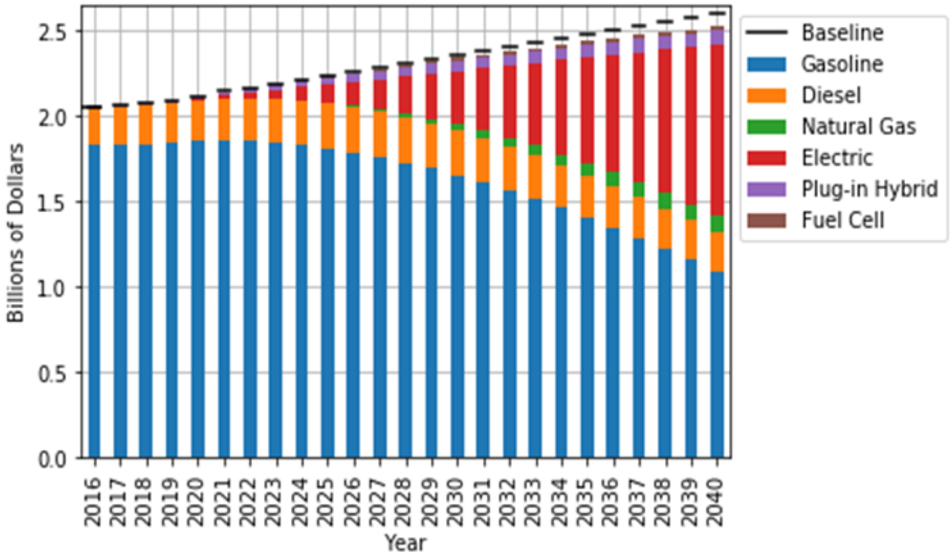
Like the Electrification Scenario, the Bridge Scenario reveals significantly higher infrastructure costs relative to the Baseline Scenario in relative terms; however, infrastructure costs remain minimal relative to other cost categories. DCFC stations needed to support light-duty BEV adoption comprise the majority of costs until the mid-2020s when light-duty L2 station costs begin to accelerate. Fast charging infrastructure is still necessary to support medium- and heavy-duty BEVs, though not at levels required by the Electrification Scenario. Natural gas infrastructure costs remain relatively low throughout the analysis period and reach approximately 3 percent of annual infrastructure costs in 2040.

Figure 40. Natural Gas as a Bridge Scenario Infrastructure Costs



Maintenance costs in the Bridge Scenario begin near $2 billion in 2016 and reach $2.5 billion annually in 2040, representing a 3 percent reduction in annual maintenance costs relative to the Baseline at the end of the analysis period. These costs are driven by BEVs, which comprise approximately 40 percent of all maintenance costs in 2040. Broken out by vehicle class, MDV and HDV sectors' total maintenance costs in this scenario are virtually equal to maintenance costs in the Baseline Scenario; it is the LDV sector that experiences maintenance cost savings due to the transition to BEVs. Diesel maintenance costs rise modestly to $250 million annually until the middle of the analysis period and decline to $200 million annually by 2040 as natural gas and electric vehicle adoption grows.

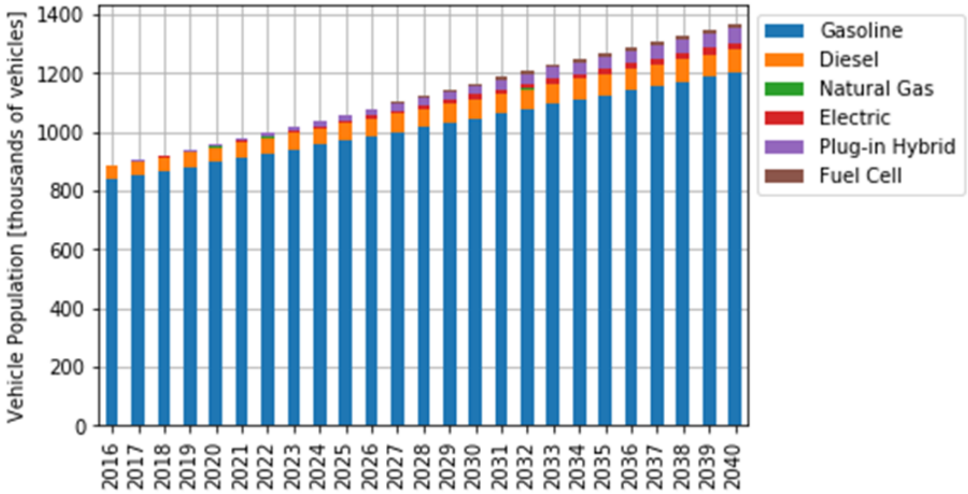
Figure 41. Natural Gas as a Bridge Scenario Maintenance Costs



5.3 Scenario C: Liquid Biofuels

In the Liquid Biofuels Scenario, the vehicle composition remains the same as the Baseline Scenario, because this scenario does not require any accelerated vehicle turnover or replacement. Gasoline LDV vehicles comprise the majority of the fleet, followed by diesel vehicles and limited quantities of alternative fuel vehicles. The primary difference in the Biofuels Scenario lies in the fuel these vehicles use. Gasoline use is offset by greater ethanol consumption, fossil natural gas is displaced by RNG, and fossil diesel is substituted for greater quantities of biodiesel and renewable diesel fuels.

Figure 42. Biofuels Scenario Vehicle Population by Fuel Type



Emissions Impacts

GHG emissions in the Biofuels Scenario begin to diverge from the Baseline Scenario in the early 2020s and decrease to approximately 5 MMT in 2040 – a 14 percent decrease relative to the Baseline in 2040. LDVs continue to drive the majority of GHG emissions throughout the analysis period and are also responsible for the greatest emissions reductions in absolute terms. In percentage terms. HDVs experience the largest decline in GHG emissions, with 2040 emissions 42 percent lower than the Baseline.

Figure 43. Biofuels Scenario CO2e Emissions by Vehicle Type

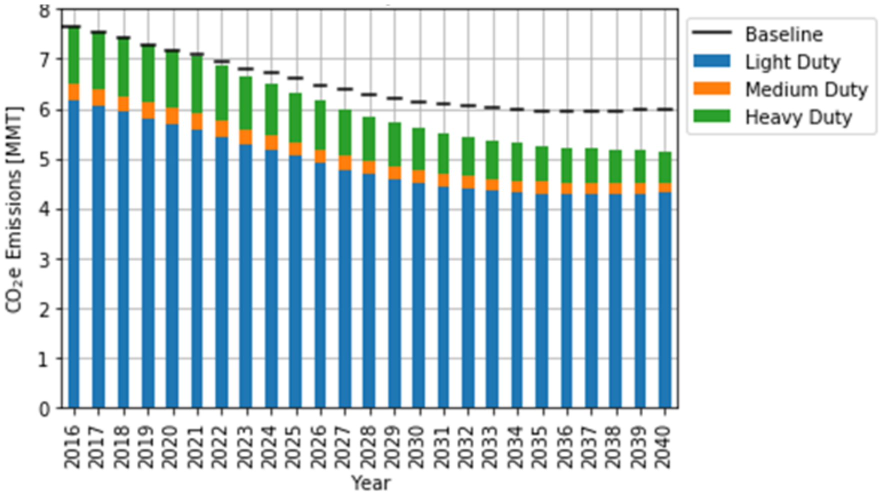
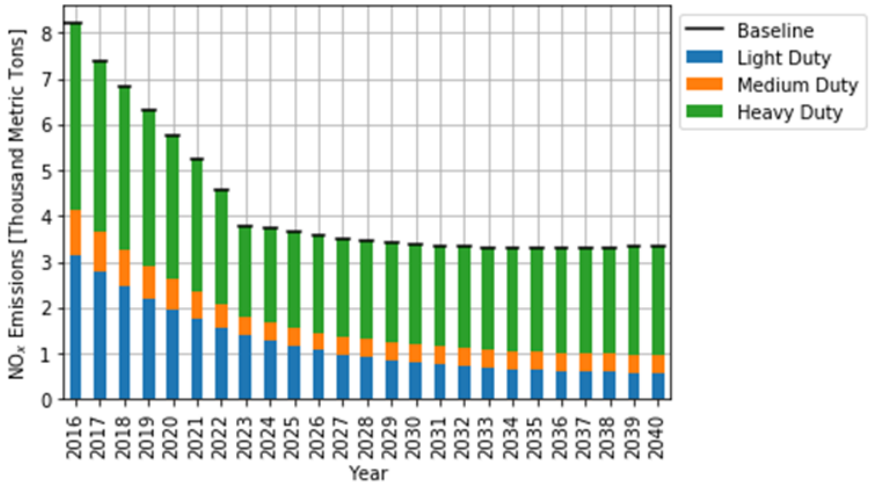


Table 26. Biofuels Scenario CO2e Emissions Impacts (MMT), 2040

Vehicle Type	Baseline Scenario	Biofuels Scenario	Difference
Light Duty	4.60	4.31	-6%
Medium Duty	0.31	0.21	-32%
Heavy Duty	1.07	0.63	-42%
Total	**5.98**	**5.15**	**-14%**

NOx emissions are unchanged in this scenario relative to the Baseline, consistent with the scenario assumption that biofuels use does not affect NOx emission rates.

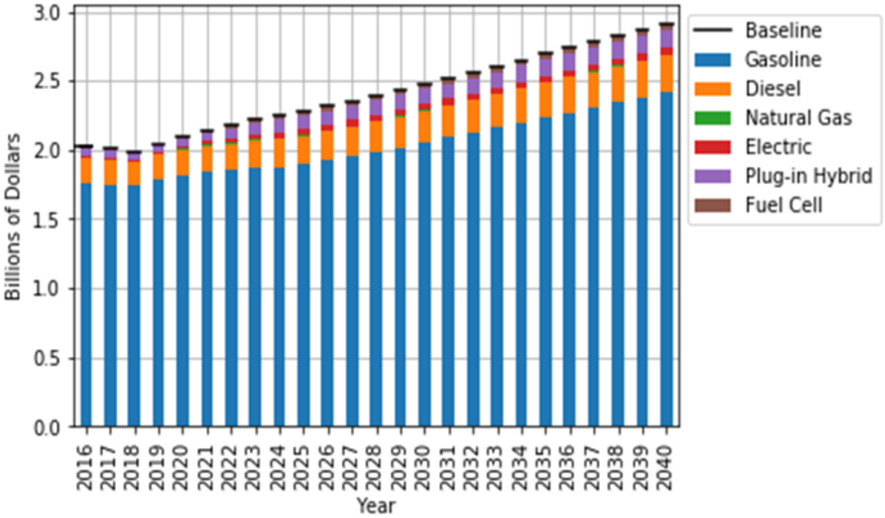
Figure 44. Biofuels Scenario NOx Emissions by Vehicle Type



Costs

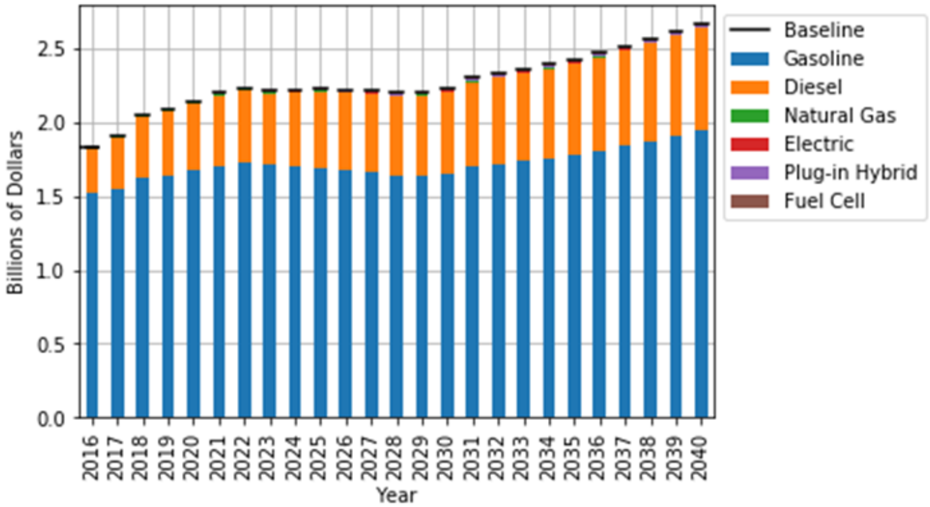
Because this scenario does not involve any changes to vehicle stock, vehicle costs in the Biofuels Scenario are identical to the vehicle costs under the Baseline Scenario. Gasoline vehicles – primarily LDVs – make up over 80 percent of total vehicle purchase costs in 2040. Modest gains made by BEVs, PHEVs, and FCVs are driven almost entirely by LDV and MDV sectors. HDVs are dominated by diesel vehicles throughout the analysis period with minor contributions from natural gas vehicles. Overall, these vehicles make up 8 percent of vehicle costs in 2040.

Figure 45. Biofuels Scenario Vehicle Purchase Costs



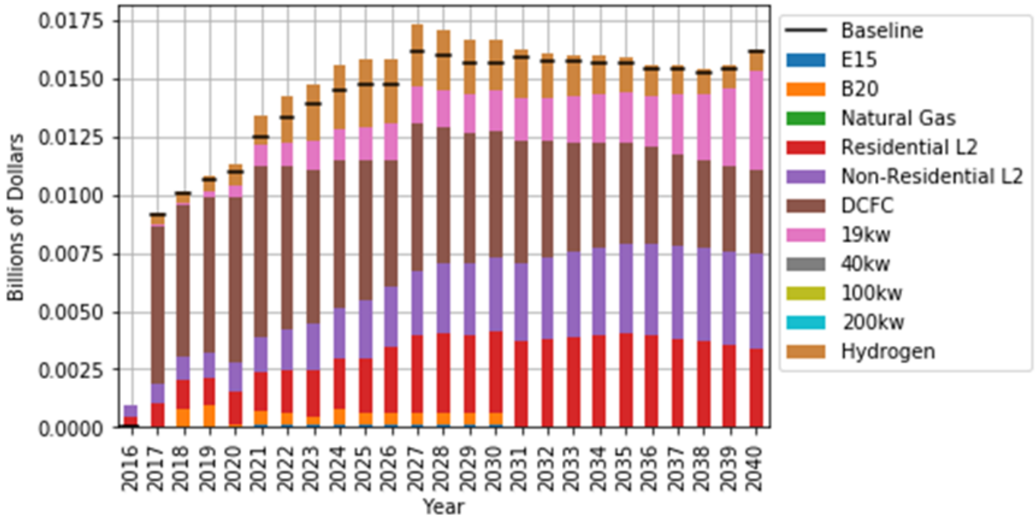
Fueling costs in the Biofuels Scenario are very similar to those in the Baseline scenario, which plateau in the mid-2020s and then continue to increase to over $2.5 billion annually in 2040. Gasoline and ethanol comprises roughly 75 percent of total fuel costs throughout the analysis period while diesel contributes to the majority of the remaining fuel costs. Annual biodiesel consumption increases to 11.7 million gallons in 2040 (relative to 5.8 million gallons in the Baseline) and annual renewable diesel consumption increases to 70.4 million gallons in 2040 (relative to 11.7 million gallons in the Baseline) while ULSD consumption declines to 35.2 million gallons in 2040. This finding suggests that the majority of diesel costs are driven by biofuels by the end of the analysis period.

Figure 46. Biofuels Scenario Fueling Costs



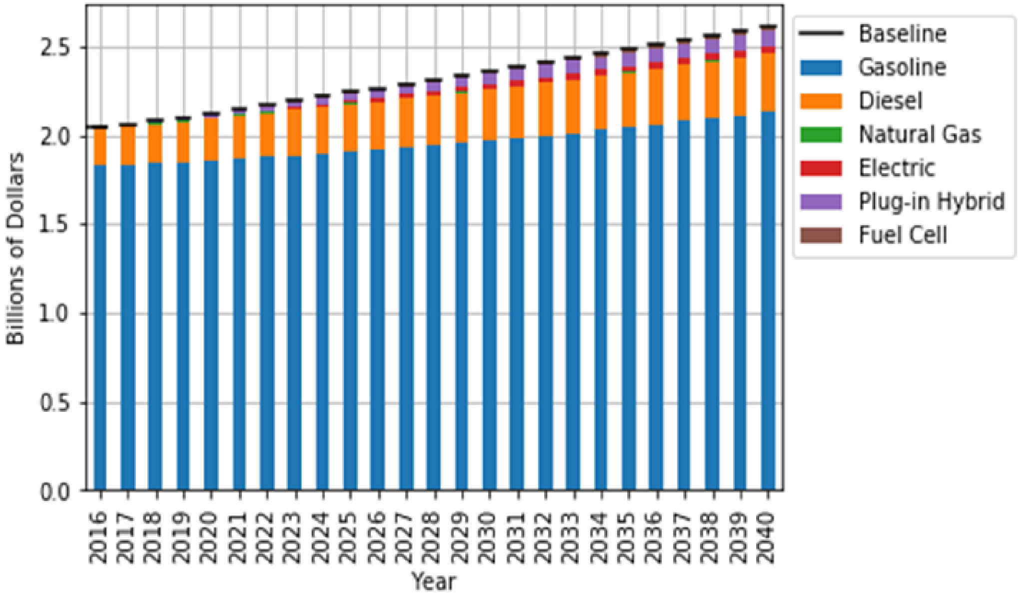
Infrastructure costs remain relatively minor in the Biofuels Scenario and slightly exceed Baseline scenario infrastructure costs. These costs continue to be driven by EV charging infrastructure costs, with minimal additional costs to support the increased use of biofuels. Infrastructure to support biodiesel and ethanol production increases infrastructure costs marginally throughout the 2020s.

Figure 47. Biofuels Scenario Infrastructure Costs



Overall, maintenance costs remain virtually identical to the Baseline Scenario – increasing gradually to over $2.5 billion in 2040. There is little cost variation among vehicle classes and fuel types relative to the Baseline. These findings are bolstered by the fact that the evaluated biofuels – when blended at appropriate levels – do not significantly impact vehicle performance or operation.

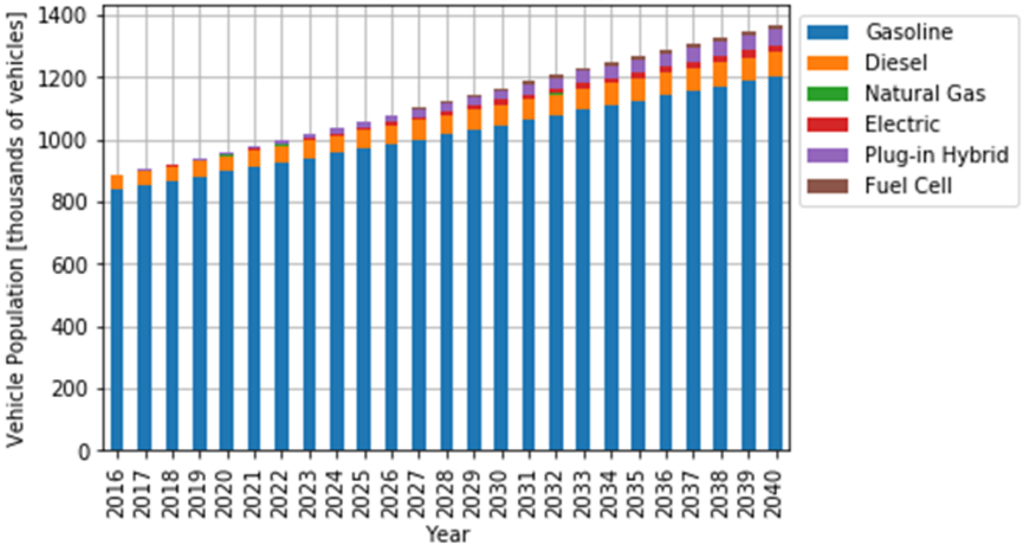
Figure 48. Biofuels Scenario Maintenance Costs



5.4 Scenario D: Biofuels and Low-NOx Diesel Engines

The Low NOx Diesel and Biofuels Scenario has the same vehicle population and composition results as the Biofuels Scenario. LDVs are dominated by gasoline powered vehicles with marginal increases in BEV, PHEV, and FCV use. MDVs and HDVs are primarily powered by diesel fuel, with modest contributions from gasoline (MDV) and natural gas (HDV). However, as of 2025, all new diesel vehicles are equipped with low NOx diesel engines, which decreases their emissions factor by 50 percent relative to a standard diesel engine.

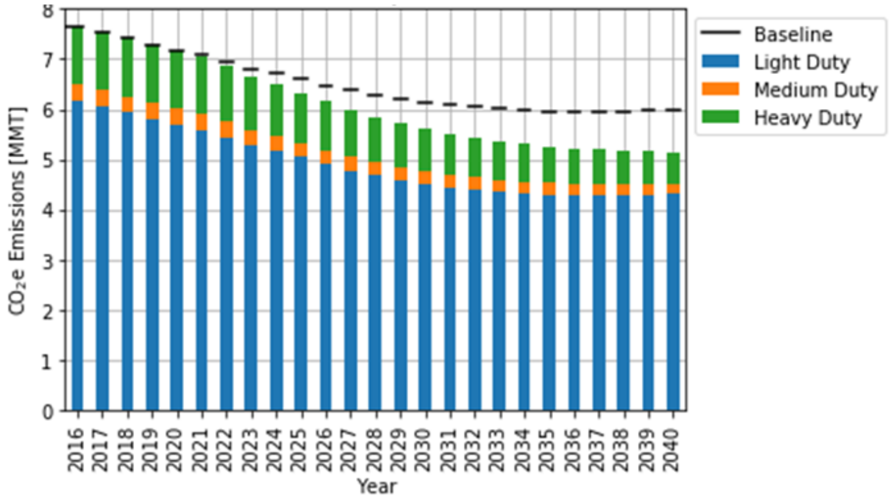
Figure 49. Low NOx Diesel & Biofuels Scenario Vehicle Population by Fuel Type



Emissions Impacts

The GHG emissions impacts of the Low NOx Diesel & Biofuels Scenario are identical to the Biofuels Scenario, shown in the figure below. GHG emissions are 14 percent lower on an annual basis in 2040 relative to the Baseline, with annual emissions exceeding 5 MMT.

Figure 50. Low NOx Diesel & Biofuels Scenario CO2e Emissions by Vehicle Type



This scenario achieves significant NOx emission reductions, as shown in the figure and table below. Total NOx emissions would be 32 percent lower in 2040 compared to the Baseline, exceeding the reductions from the Electrification and Natural Gas as a Bridge Scenarios. The NOx reductions occur almost exclusively among MDV and HDV types, since this scenario effects NOx emissions only for diesel engines.

Figure 51. Low NOx Diesel & Biofuels Scenario NOx Emissions by Vehicle Type

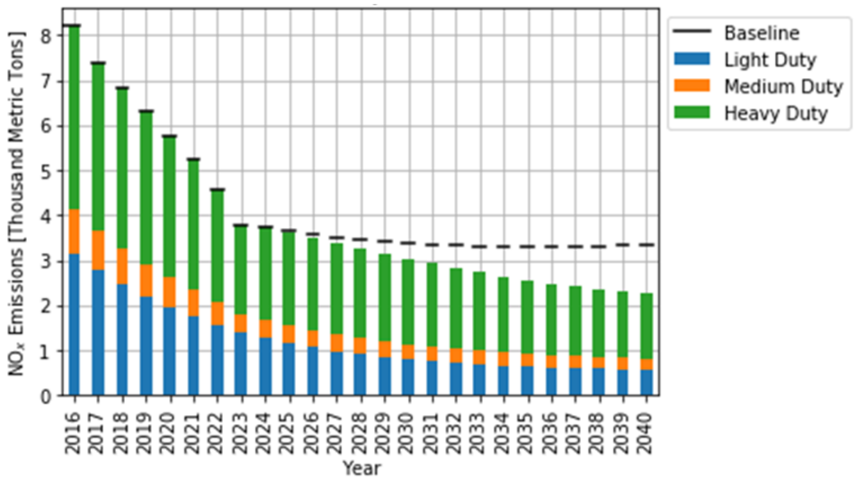


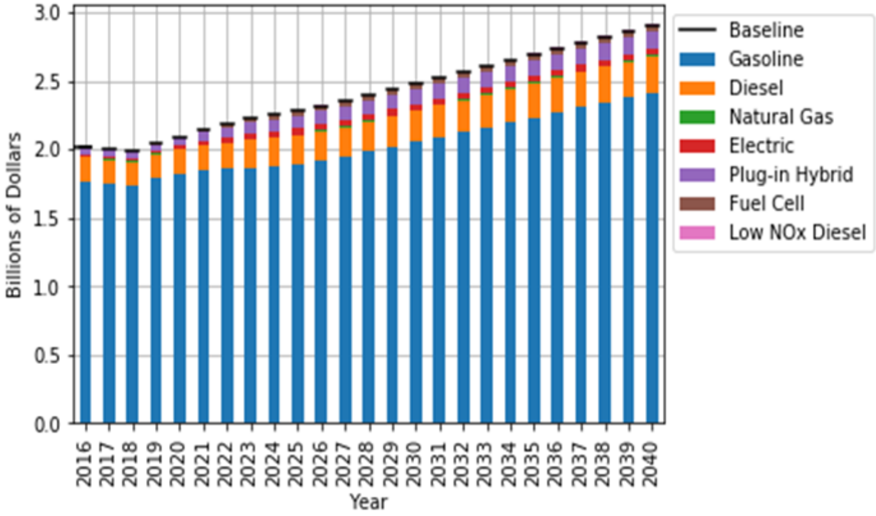
Table 27. Low NOx Diesel & Biofuels Scenario NOx Emissions Impacts (thousand MT), 2040

Vehicle Type	Baseline Scenario	Biofuels + Low NOx Diesel Scenario	Difference
Light Duty	0.58	0.57	-1%
Medium Duty	0.40	0.25	-38%
Heavy Duty	2.37	1.46	-38%
Total	**3.34**	**2.28**	**-32%**

Costs

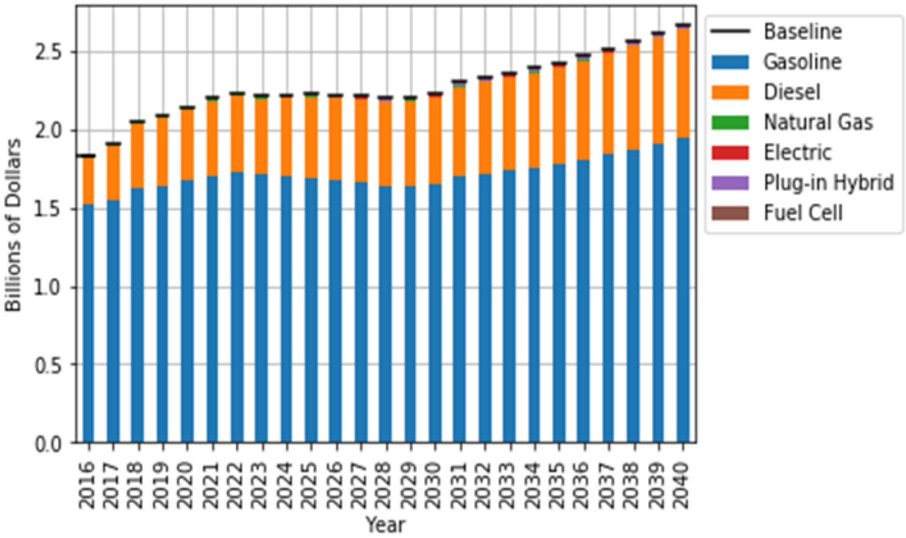
The vehicle costs in this scenario follow the Baseline Scenario vehicle costs. Gasoline remains the primary fuel for LDVs while conventional diesel vehicles continue to dominate MDV and HDV sectors.

Figure 52. Low NOx Diesel & Biofuels Scenario Vehicle Purchase Costs



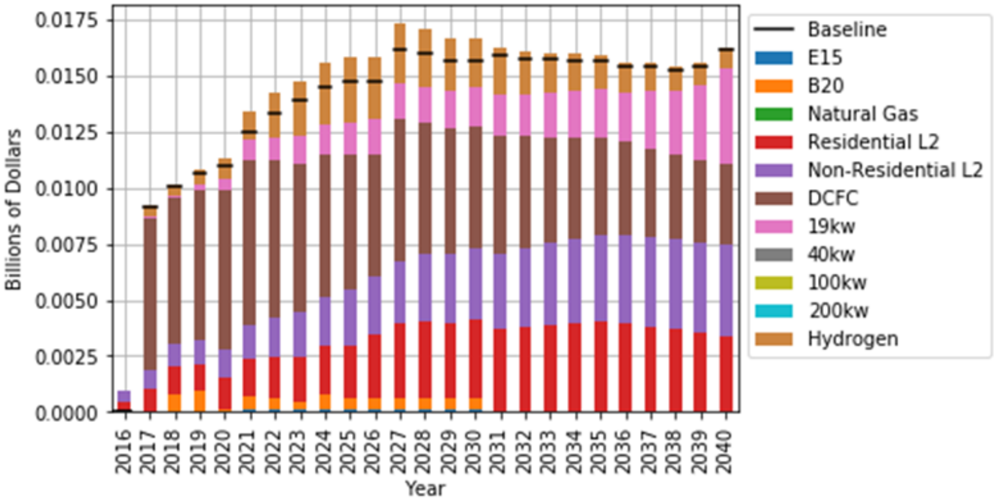
Fueling costs remain nearly equivalent to the Baseline Scenario, with gasoline and diesel contributing to the majority of total fuel costs throughout the analysis period. Natural gas, electricity, and hydrogen do not add significantly to fuel costs given the limited penetration of these vehicles in this scenario.

Figure 53. Low NOx Diesel & Biofuels Scenario Fueling Costs



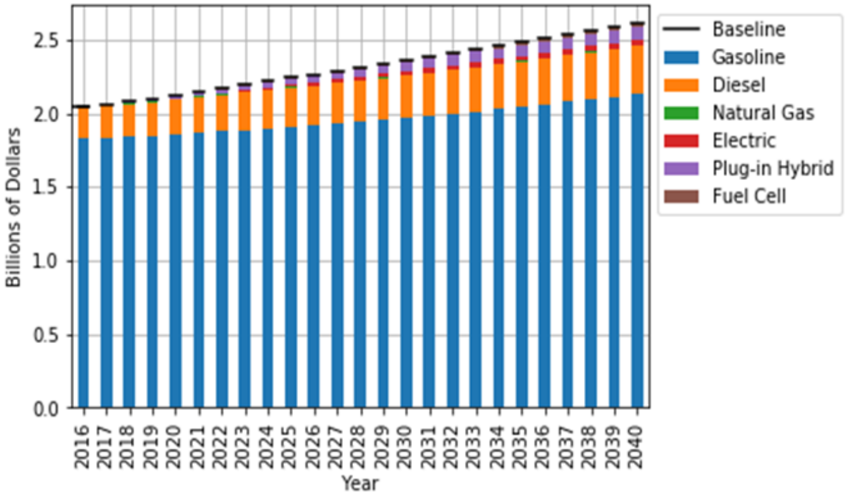
The Low NOx Diesel and Biofuels Scenario does not yield significant infrastructure costs or vary substantially from the Baseline Scenario. The bulk of these costs are driven by EV charging infrastructure investments, with minor biofuel (B20 and E15) contributions in the 2020s. The minimal variation in costs stems from the observation that low NOx diesel trucks do not require new fueling infrastructure to support their operation. Similarly, biofuels require only modest fueling infrastructure investments and in some cases, can leverage existing assets used to support gasoline and diesel refueling.

Figure 54. Low NOx Diesel & Biofuels Scenario Infrastructure Costs



Maintenance costs remain virtually unchanged relative to the Baseline Scenario. Diesel vehicles comprise approximately 10-15 percent of maintenance costs throughout the analysis period. The low quantities of non-gasoline and non-diesel vehicles limits their contribution to maintenance costs at approximately 6 percent of total maintenance costs in 2040.

Figure 55. Low NOx Diesel & Biofuels Scenario Maintenance Costs



5.5 Summary of Results

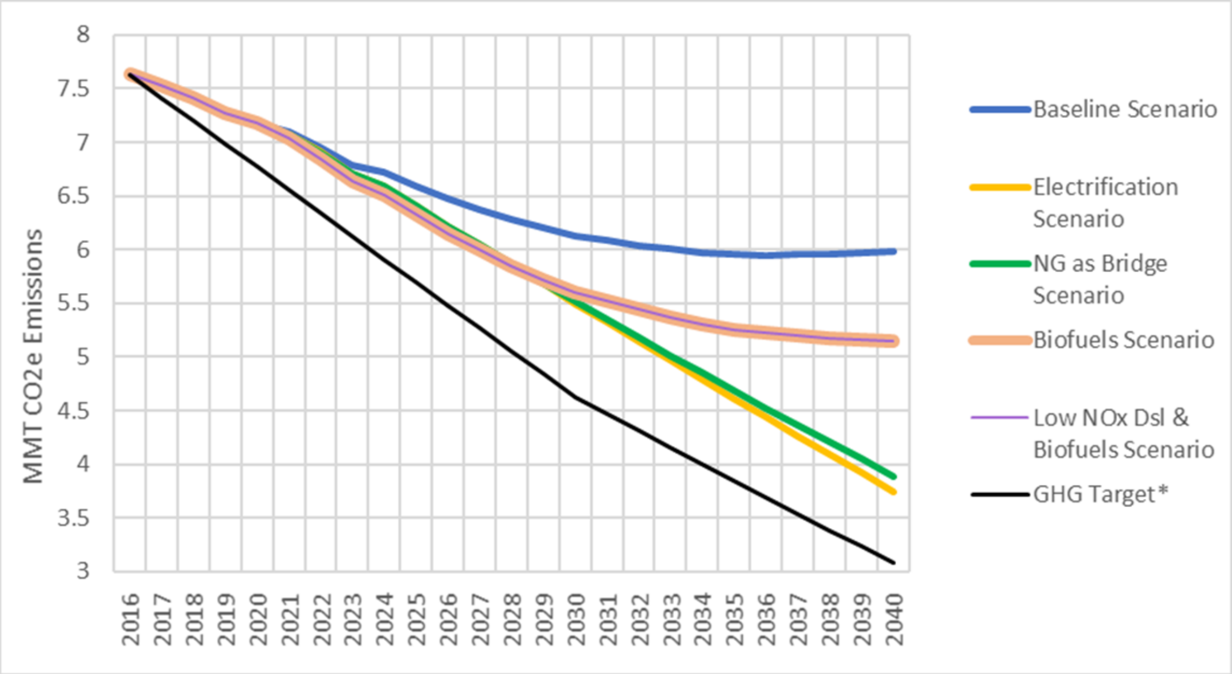
The scenarios evaluated present a range of emissions and cost outcomes for San Bernardino County's on-road transportation sector. These results are heavily influenced by the availability and adoption of various vehicle technologies and alternative fuels. The following figures present a comparison of all scenarios and their performance on several key metrics: GHG emissions, NOx emissions, and total cost.

GHG Emissions

The figure below shows the GHG emissions under the Baseline and four analysis scenarios. The Electrification and Natural Gas as a Bridge Scenarios provide the largest reductions and are quite similar in terms of their GHG impacts. The Biofuels and Low NOx Diesel & Biofuels Scenarios are identical in terms of their GHG impacts, since the low NOx diesel engines do not affect GHG emissions. These two scenarios follow a similar emissions trajectory as Electrification and Natural Gas as a Bridge through 2030, but provide only modest additional reductions after 2030.

By way of comparison, the figure shows a GHG reduction target based on the statewide GHG reduction for all sectors necessary to achieve California's 2030 emissions target. As described in the state's 2017 Climate Change Scoping Plan, in order to achieve the state's 2030 target, statewide emissions must decline from 429 MMT in 2016 to 260 MMT in 2030, a 39% reduction. None of the four scenarios achieve this level of reduction by 2030.

Figure 56. Comparison of CO2e Emissions by Scenario



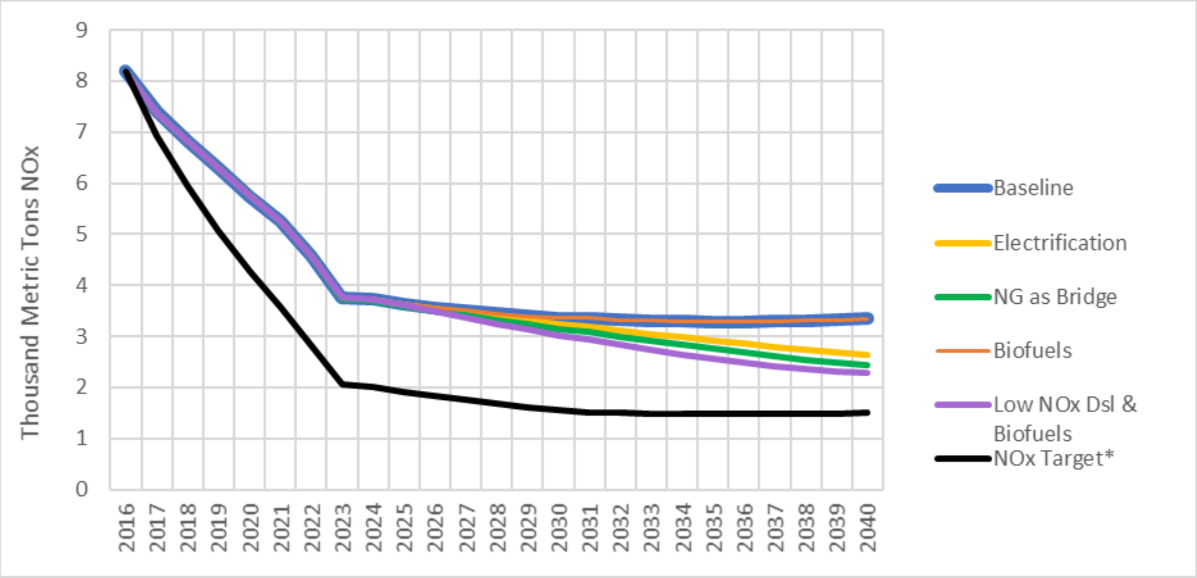
* GHG target reflects the percent reductions needed statewide from all sources to achieve California's 2030 and 2050 emissions targets.

NOx Emissions

The figure below illustrates the annual NOx emissions of the scenarios over the analysis period and their relationship to the NOx emissions target identified for the study area. The NOx reduction target is based on the 2016 AQMD Air Quality Management Plan, which called for a 45% NOx reduction from Baseline in 2023 and a 55% reduction from Baseline in 2031, considering all sources of NOx (not just on-road vehicles).

NOx emissions under all scenarios rapidly decline until 2023 – driven by CARB's Truck and Bus regulation. Beyond 2023, all scenarios gradually reduce NOx emissions, with the Low NOx Diesel & Biofuels Scenario achieving the best performance in terms of NOx reductions over the remainder of the analysis period. Given that diesel HDVs are the largest contributor to on-road NOx emissions, the adoption of low NOx diesel engines can have an outsized impact on reducing these emissions as other alternative fuels achieve scale in the market. The Natural Gas as a Bridge and Electrification Scenarios also achieve significant NOx reductions, albeit at a slightly more gradual rate. The Biofuels Scenario has no impact on NOx emissions and thus mirrors the Baseline Scenario emissions. None of the scenarios evaluated achieve the NOx emission reductions identified by the study area NOx emission target.

Figure 57. Comparison of NOx Emissions by Scenario

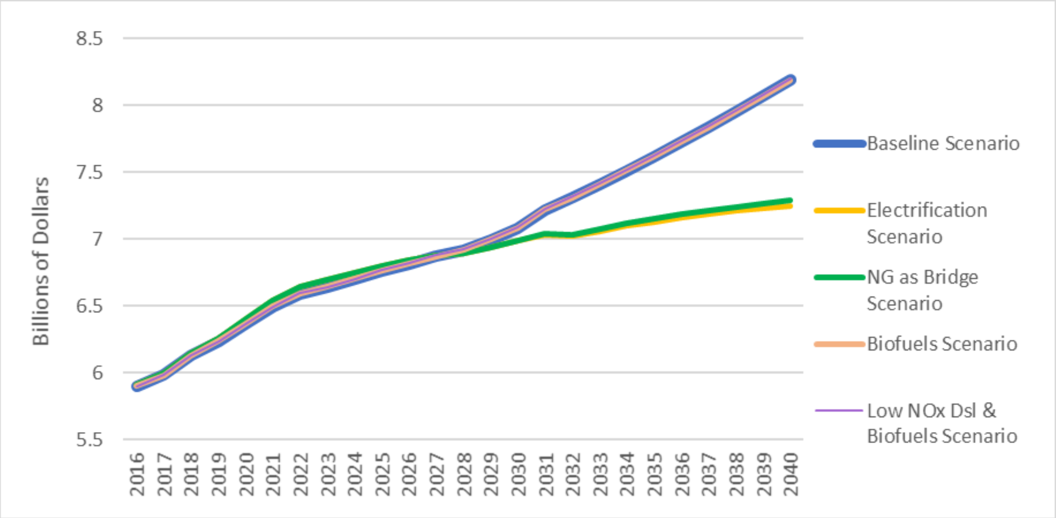


* NOx target reflects the percent reduction in NOx emissions in the South Coast Air Basin from all sources necessary to achieve attainment with the federal ozone standard, as presented in the 2016 Air Quality Management Plan

Costs

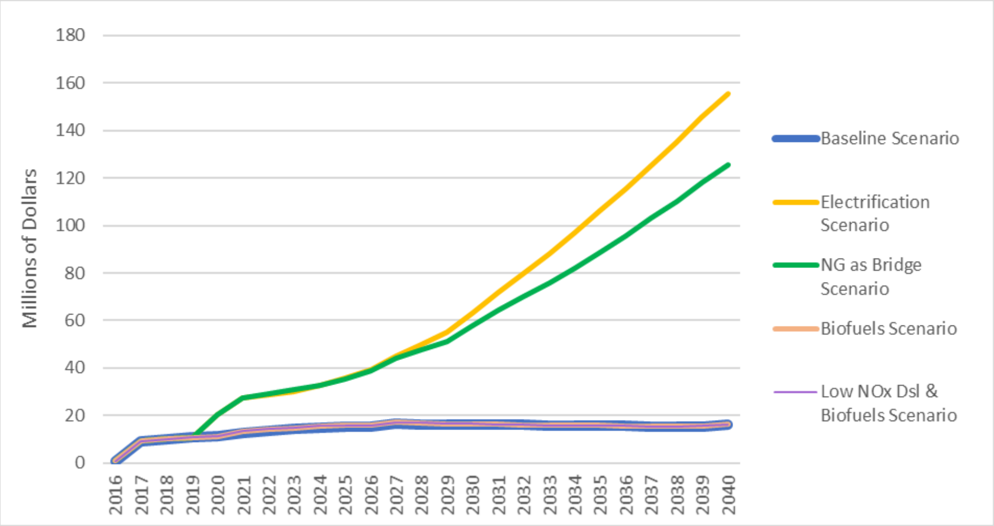
The following figure shows the aggregate annual costs for each scenario over the analysis period. Aggregate costs for all scenarios are virtually identical through 2028, after which the Electrification and Natural Gas as a Bridge Scenarios diverge with lower costs. This is driven by the assumption that fueling costs for electric and natural gas vehicles will be lower than most gasoline and diesel vehicles in the latter years of analysis, as discussed in Section 4. Aggregate costs for Biofuels and Low NOx Diesel & Biofuels Scenarios are nearly identical to the Baseline Scenario costs, since these scenario do not involve addition vehicle purchase costs and have similar operation and maintenance costs.

Figure 58. Comparison of Total Cost by Scenario



The aggregate costs of each scenario are dominated by vehicle purchase costs, fueling costs, and maintenance costs, most of which would be borne by the vehicle owner. In contrast, fueling infrastructure costs account for only 0.2 percent to 2.1 percent of the aggregate costs across all scenarios and analysis years. However, fueling infrastructure costs are important because they would likely be at least partly supported by government agencies seeking to encourage the deployment and use of clean vehicles. The figure below shows only the fueling infrastructure costs for the scenarios. The Electrification Scenario carries the highest costs, rising to nearly $160 million annually by 2040. It is followed by the Natural Gas as a Bridge Scenario, which reaches $125 million per year by 2040. In contrast, the Biofuels and Low NOx Diesel & Biofuels Scenarios are virtually identical to the Baseline in terms of fueling infrastructure costs. The is primarily due to assumption that biofuels can be dispensed at existing fueling stations, often blended with conventional fuels.

Figure 59. Comparison of Fueling Infrastructure Costs by Scenario



The two figures below illustrate how each scenario compares to the Baseline Scenario in terms of cumulative costs between 2016-2030 and 2016-2040. These charts show only the difference between the Baseline and each scenario (i.e., the Baseline is zero in these charts). Overall, the Biofuels and Low NOx Diesel & Biofuels Scenarios generally track the Baseline costs throughout the analysis period. These scenarios require a small incremental investment in infrastructure ($6 million over the analysis period) – an amount that is much smaller than the other two scenarios so barely appears in the charts.

The Electrification and Natural Gas as a Bridge Scenarios differ significantly from the Baseline Scenario. Both require significant incremental vehicle purchase costs, particularly in the early years of analysis. Between 2016 and 2030, these two scenarios involve a cumulative purchase cost increment of more than $600 million. By 2040, the cumulative vehicle purchase cost increment has declined, reflecting the input assumption that EVs will become cheaper than conventional vehicles in the latter years of the analysis. Note that the vehicle purchase costs could be borne entirely by the vehicle owner, or a portion could be borne by government agencies in the form of a subsidy.

The Electrification and Bridge Scenarios result in large cost savings for fueling costs and, to a lesser extent, maintenance costs. From 2016 to 2030, the total savings in fueling and maintenance costs exceeds $700 million for both scenarios, more than offsetting the incremental vehicle purchase costs.

Considering cumulative costs out to 2040, fueling cost savings dominate the total incremental cost of these two scenarios.

The incremental cumulative fueling infrastructure costs total approximately $250 million for both the Electrification and Bridge Scenarios by 2030, and grow to more than $1 billion by 2040. Infrastructure costs are slightly higher under the Electrification Scenario than the Bridge Scenario. Overall, considering the full analysis period out to 2040, the Electrification and Bridge Scenarios offer the greatest potential cumulative cost savings relative to the Baseline Scenario.

Figure 60. Incremental Cumulative Costs (Relative to the Baseline), 2016-2030

Figure 61. Incremental Cumulative Costs (Relative to the Baseline), 2016-2040