Comparison of Medium- and Heavy-Duty Technologies in California

Executive Summary

December 2019

Submitted by:
ICF
75 East Santa Clara St.
Suite 600
San Jose, CA 95113

Prepared for:

California Electric Transportation Coalition
Natural Resources Defense Council

In Partnership With:
    Union of Concerned Scientists
    Earthjustice
    BYD
    Ceres
    NextGen Climate America

With Advisory Support From:
    University of California, Davis Policy Institute for Energy, Environment and the Economy
East Yard Communities for Environmental Justice

I. Introduction

Federal and state air quality standards and climate goals, and the subsequent policies and plans to meet them, are the driving force behind the adoption of medium- and heavy-duty (MD and HD) alternative fuel vehicles. Understanding the type and pace of alternative vehicle technology and fuel implementation required for California to achieve its public health goals is extremely important for developing complementary policies and regulations.

This report presents the results of a comprehensive study to compare the emission, cost, and economic and jobs impacts of alternative technologies for the MD and HD transportation sector. The report provides in-depth comparisons of:

- Emission reductions achieved by alternative fuel technology-based fleetwide scenarios.
- The total cost of ownership for various vehicle and fuel combinations.
- The economic and jobs impact in California of the alternative scenarios.

This study was commissioned by the California Electric Transportation Coalition (CalETC) and the Natural Resources Defense Council (NRDC). The study was prepared in partnership with the Union of Concerned Scientists, Earthjustice, BYD, Ceres, and NextGen Climate America, with advisory support from the University of California, Davis Policy Institute for Energy, Environment and the Economy, and East Yard Communities for Environmental Justice.

The report offers three assessments that collectively provide important insights into the implications of various alternative fuel pathways, and a fourth component that outlines a “balanced scorecard” approach that allows a more complete and nuanced evaluation of different policy options than has typically been the case. The elements of the report are:

- Emission Impacts Scenario Analysis
- Total Cost of Ownership Technology Assessment
- Economic Analysis
- Balanced Scorecard

The fundamental conclusion that emerges from this analysis is that battery electric trucks and buses are the most promising technology to reach California’s mid- to long-term goals, from both an economic and environmental perspective. The remainder of this Executive Summary describes the findings in support of that conclusion in more detail.

II. Emission Impacts Scenario Analysis

The purpose of the emission impacts scenario analysis is to determine if alternative fuels and electrification in the MD and HD sectors can meet California’s near- and long-term policy objectives. The fuels included in the scenario analysis included biodiesel and renewable diesel, natural gas (both fossil and renewable), and electricity. (Hydrogen fuel was included in the Total Cost of Ownership analysis described below, but due to ongoing projected high costs for vehicles and infrastructure and limitations on data, the results of the TCO analysis for hydrogen-fueled vehicles were not carried forward into the scenario analysis or the economic analysis.)

The scenarios presented include:

1. **Current Policies (baseline)**. The Current Policies scenario includes currently adopted policies (state and federal laws, regulations, and legislative actions adopted as of December 2017), and the Sustainable Freight Action Plan. Renewable diesel and biodiesel are assumed to reach up to 1.5 billion gallons annually. The Current Policies scenario provides the baseline against which the remaining scenarios are compared.
2. **Diesel**. The Diesel scenario examines how close current fuels and infrastructure could bring California to its 2030 and 2050 targets. It adds low NOx diesel engines starting in 2024, and additional diesel fuel economy improvements post-2027, to the suite of policies contained in the baseline. These changes are also carried over into each of the remaining scenarios.
3. **Electricity**. The Electricity scenario attempts to meet 2030 and 2050 GHG and NOx emission targets with an emphasis on greater penetration of electric trucks and buses relative to the Natural Gas and Diesel scenarios.
4. **Natural Gas**. The Natural Gas scenario attempts to meet 2030 and 2050 targets with an emphasis on greater penetration of natural gas trucks and buses relative to the Electricity and scenarios.
5. **Electricity Max**. The Electricity Max scenario is intended to illustrate the upper limit of new MD and HD electrification in helping to meet the 2031 NOx target and in achieving additional GHG reductions. This scenario assumes that 100 percent of MD and HD sales are electric starting in 2024.

The key messages and findings from the Emission Impacts Scenario Analysis include:

- Widespread electrification beyond existing and proposed policies is required to meet both 2030 and 2050 GHG goals and to significantly help in achieving the NOx reductions required to meet federal ambient air quality standards.
- Pathways relying primarily on combustion technologies (diesel and natural gas trucks) and biofuels are insufficient for meeting 2030 and 2050 climate and air quality goals
- Accelerating electric truck and bus deployment beyond what is required to meet 2030 climate targets would provide greater NOx reductions by 2031. However, for MD and HD vehicles to achieve their proportional NOx reductions to meet 2031 requirements, regulations or policies to retire pre-2024 engines are likely necessary, or additional NOx reductions from other sectors are needed to make up the gap.
- The renewable natural gas (RNG) supply limit of 750 million diesel gallon equivalents (DGE) in the transportation sector, based on California's potential from low-carbon-intensity waste feedstocks, puts a cap on the GHG reduction potential from natural gas vehicles.[1]

Figure ES- 1 shows GHG and tailpipe NOx emissions from all of the scenarios examined, as compared to the state's GHG (through 2050) and NOx (2031) targets. The only scenarios that

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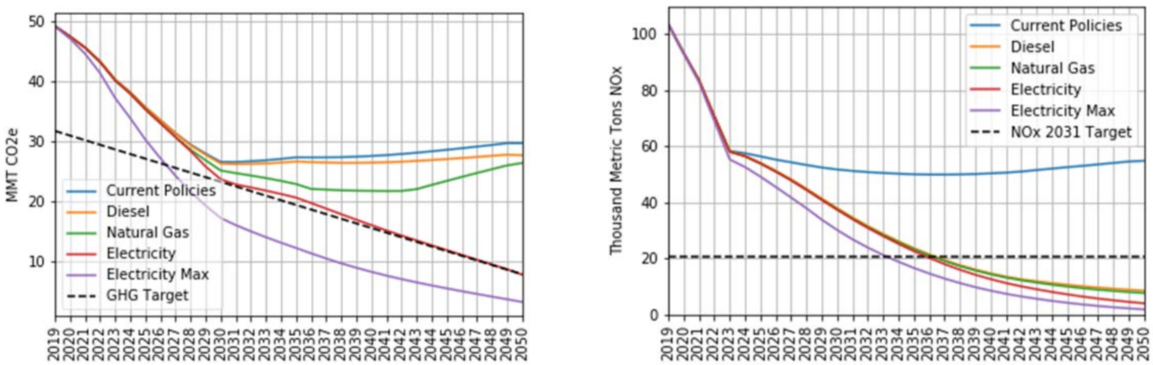
[1] Section II.4 of the Emission Impact Scenario Analysis contains additional details and methodology for determining the supply limit of RNG.

fully achieve the state’s GHG goals are Electricity and Electricity Max. The Diesel and Natural Gas scenarios achieve significant GHG reductions around 2030, but transportation emissions in those scenarios do not substantially decline afterwards due to the sector exhausting the availability of renewable fuels. None of the scenarios examined achieve the state’s 2031 NOx target. The Electricity Max scenario meets the 2031 NOx target in 2033, and the Electricity, Natural Gas, and Diesel scenarios achieve the 2031 NOx target between 2036 and 2037.

Figure ES- 1 Scenario GHG Emission (MMT CO_2e/yr.) and Tailpipe NOx Emission Comparison



The Scenario Analysis shows that increased electrification, beyond existing and proposed policies, is required to meet both 2030 and 2050 GHG goals and to significantly help in meeting 2031 NOx requirements. The Electricity scenario, which results in 100,000 electric MD and HD electric vehicles in 2030 and over 1.4 million in 2050, is the only scenario (outside of the Electricity Max “upper limit” scenario) able to achieve both the 2030 and 2050 GHG goals. Importantly, if the reductions from other measures built into the scenarios--increased diesel fuel efficiency, use of biodiesel and renewable diesel for compliance with the low carbon fuel standard (LCFS), and 25 percent fuel consumption reductions from sustainable freight-- are not achieved, electric trucks will have to play an even more important role in achieving GHG reduction goals.

The Diesel, Natural Gas, Electricity, and Electricity Max scenarios are all able to achieve significant tailpipe NOx emission reductions compared to the Current Policies scenario. Battery electric vehicles (BEVs) and natural gas vehicles (NGVs) achieve additional emission reductions compared to the Diesel scenario, even assuming a low-NOx diesel rule. In the long term, the Electricity scenario can achieve discernable NOx reductions compared to the Diesel and Natural Gas scenarios. When upstream NOx emissions are included in a full lifecycle analysis, the Electricity and Electricity Max scenarios achieve approximately 30-45% greater annual lifecycle NOx emission reductions in 2050 than the Diesel and Natural Gas scenarios.

III. Total Cost of Ownership Technology Assessment

This portion of the report assesses the total cost of ownership (TCO) of MD and HD technologies. The TCO as calculated here is the cumulative cost to the first owner of a vehicle, including vehicle capital (purchase price minus residual value), operation and maintenance (which includes the cost of fuel), and any necessary infrastructure, minus applicable incentives and regulatory requirements. The TCO calculation was performed for fourteen vehicle sizes and applications from Class 2b to Class 8 trucks and buses, and across fuels including diesel, natural gas and renewable natural gas (including landfill gas (LFG)), electricity, and hydrogen. Some key findings from this analysis include:

- Costs for electric MD and HD vehicles are falling, largely due to the rapidly declining cost of batteries. While the value of Low Carbon Fuel Standard (LCFS) credits, along with direct vehicle incentives such as the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP), make the economics attractive for fleet operators and owners now, by 2030 battery electric trucks and buses are projected to achieve favorable total cost of ownership across almost all classes evaluated, even absent incentives.
- Utility programs providing low- and off-peak rate periods and mitigating demand charges for MD and HD technologies are critical for electric vehicle and fleet owners. Current programs offered by utilities in California are allowing fleet owners to take advantage of the potentially lower fuel costs compared to diesel or natural gas vehicles.

Figure ES- 2 provides an example of the results of the TCO analysis, in this case for Class 8 drayage trucks. Results are shown for drayage trucks operating on diesel, electricity, CNG/LFG (compressed natural gas sourced from landfill gas), and hydrogen, today and in 2030. Cost components (vehicle, operation and maintenance, infrastructure) are shown as positives above the $0 line, and policies that reduce the cost (HVIP, LCFS, utility incentives) are shown as negatives below the $0 line. The black circles and related dollar amounts denote the total cost of ownership--the total of the cost components minus any incentives. The full report provides similar analysis for fourteen vehicle classes and applications.

Figure ES- 2 shows that HVIP incentives are currently critical for electric Class 8 drayage trucks to have the lowest TCO. By 2030, however, even without HVIP, the electric truck can achieve the lowest TCO as a result of reductions in vehicle purchase price and lower operating costs. New rate structures combined with optimized charging around low- or off-peak periods could result in significant fuel cost savings for electric trucks and buses.[2] To maximize these potential fuel savings, it will be important to assist fleet operators, especially operators of smaller truck fleets, in the transition from liquid refueling to charging to take advantage of these lower rates.

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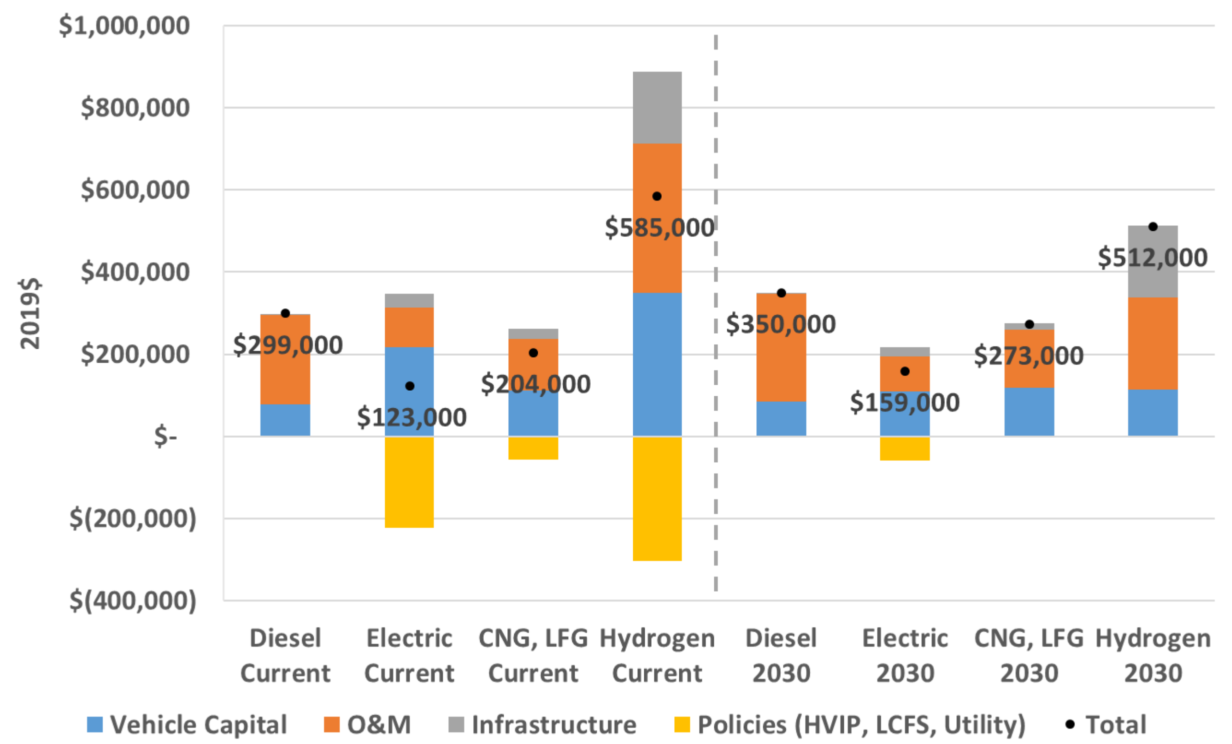
[2] The analysis was based on currently available or proposed rate structures. Unanticipated limits to charging off-peak or future potential electricity rate increases would impact the analysis but likely would not change the overall conclusion that electric technologies will have a lower TCO than conventional and other alternative technologies in 2030.

Figure ES- 2 Class 8 Drayage Truck TCO Analysis Results[3,45]



IV. Economic Analysis

The economic analysis projects the net economic impact of the previously-defined scenarios (Current Policies, Diesel, Natural Gas, Electricity, and Electricity Max), taking into account direct, indirect and induced effects and the impact of contraction in the gasoline and diesel sectors. The economic modeling considered spending on vehicles, infrastructure and fuel, and reinvestment of a portion of fuel savings into increased production by the industry sectors most involved in MD and HD trucking.

Using the IMPLAN model (a regional input-output economic model), ICF obtained results for four commonly used metrics, consistent with best practices across economic impact analyses:

1. **Employment**: The job-years created in each industry, based on the output per worker for each industry.
2. **Labor income**: Includes all forms of employment income generated by the direct input, including employee compensation (wages and benefits) and proprietor income.

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[3] The analysis is based on natural gas trucks with 9L engines. ICF also ran the analysis for natural gas trucks with 12L engines which results in a vehicle cost increase of approximately $22,000, taking into account the increased sales price ($30,000) and residual value of the increased incremental cost (approximately $8,000).

[4] This analysis does not include road taxes, licensing, and insurance. HVIP and utility programs only apply to "current" cost estimates.

[5] CNG/LFG and hydrogen earn LCFS credit in 2030 but the amounts are so small that they are not visible in this chart.

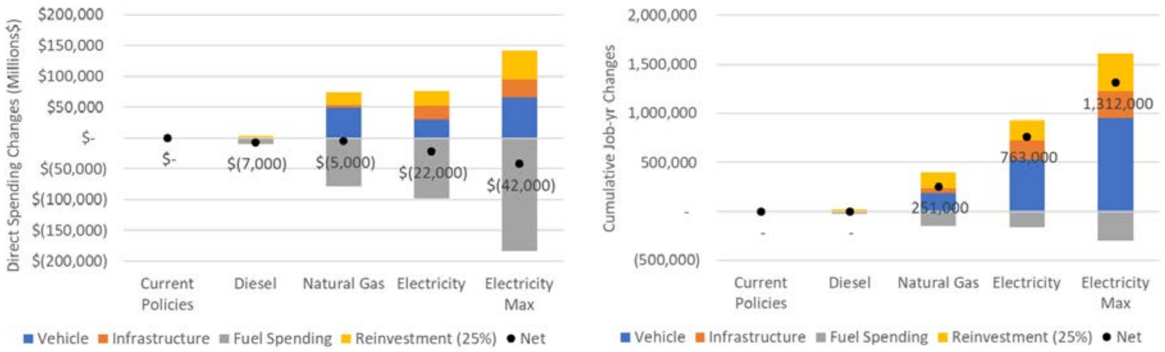
3. **Gross regional product (GRP)**: The net value of output, including labor income, indirect business taxes, and business income.
4. **Industry activity**: The total value of industry activity generated by the direct spending.

Stated most simply, transitioning away from petroleum fuels allows funds that would otherwise flow out of California's economy to be retained here, which increases jobs and local economic activity. The Economic Analysis quantified those impacts, and found that:

- Truck electrification provides greater benefits to the economy as a whole than other alternatives evaluated. Investment in BEVs and BEV infrastructure results in greater net employment, Gross Regional Product, and industrial activity per dollar spent compared to natural gas vehicles and infrastructure.
- Electrification scenarios result in about a doubling of incremental GRP and jobs in the MD/HD truck sector relative to natural gas or diesel. The Electricity scenario adds about 50 percent more jobs economy-wide per million dollars invested than the Natural Gas scenario, and Electricity Max adds almost 100 percent more.
- Decreased fossil fuel consumption reduces employment in the retail gas station, oil and gas, and crude petroleum extraction sectors, but 4 to 5 times more jobs are created in other sectors of the economy, resulting in net employment gains.
- The increased electric vehicle deployment in the Electricity Max scenario (approximately 800,000 vehicles in 2030 as compared to 100,000 in the Electricity scenario) resulted in additional positive economic impacts, including greater employment, gross regional product (GRP), and industrial activity per dollar spent.
- All of the alternative fuel scenarios show a reduction in net direct spending and overall positive employment and economic impacts compared to the Current Policies scenario. This is due to the magnitude of fuel savings combined with the positive economic impacts from the reinvestment of fuel savings more than offsetting negative impacts from reduced fuel spending.

Figure ES-3 shows cumulative changes from 2019 to 2050 in direct spending and employment relative to the Current Policies scenario from the direct spending on vehicle, infrastructure, fuel, and reinvestment of fuel savings. The modeling considered direct, indirect and induced impacts. All scenarios have significant reductions in net fuel spending and the Natural Gas, Electricity, and Electricity Max scenarios show significant investment in infrastructure, vehicles, and fuel savings reinvestment compared to the Current Policies scenario.

Figure ES-3. Cumulative Direct Spending (Millions$) and
Employment (Job-years) Changes from 2019-2050 Relative to Current Policies



V. Balanced Scorecard

The objective of the balanced scorecard was to develop a framework to compare different alternative fuel technologies across a number of dimensions. The comparison includes technical, economic, environmental, and regulatory considerations, using a combination of quantitative (where available) and qualitative factors.

Many current emission reduction and technology funding mechanisms use scoring and ranking systems focused on a singular pollutant or goal, followed by determining cost-effectiveness around reducing that pollutant or meeting that singular goal (e.g., diesel particulate matter reduction policies). Sometimes, these previous frameworks have even favored fossil fuel technologies over advanced vehicle technologies because their analysis was limited in scope. With California's near-term and long-term goals for multiple pollutant reductions, it is necessary to be able to evaluate technologies not just for singular pollutant or emissions goals, but also for how they fit into the broader landscape of California policies.

The project team developed a comprehensive yet workable set of measures that collectively capture the many dimensions important to long term policy formulation. That effort resulted in a Balanced Scorecard that is divided into five sections, and combines both quantitative and qualitative technological, economic, and policy assessments. The five categories of the Balanced Scorecard are:

- Commercialization status
- Barriers today
- Environmental considerations
- Policy alignment
- Cost considerations

The Balanced Scorecard is rated using a combination of qualitative and quantitative analytical and market assessments made by ICF, and then reported out using a five-color scheme. The five-color scheme is shown in the following spectrum—with red the lowest rating on the left and green the highest rating on the right.

🟥 🟧 🟠 🟨 🟩

Where appropriate, the analytical assessment is reported out on an absolute basis in the context of the cell, but the rating will typically be determined on a relative basis. Additional detail regarding the key components of ICF's assessment for each element of the Balanced Scorecard is provided in the ICF report.

Table ES 1 provides an example of the application of the Balanced Scorecard to the Class 8 tractor, short haul and drayage truck applications. An explanation of the rationale for the scoring is provided in the full report, along with scorecards developed for all of the vehicle categories included in this analysis.

Table ES 1. Class 8 Tractor, Short Haul and Drayage Truck Balanced Scorecard

Categories	Class 8 Tractor, Short Haul, and Drayage Truck						
	Diesel	Diesel Hybrid	Renewable Diesel	Electricity	Fossil NG - Low NOx	LFG /RNG – Low NOx	Hydrogen
Commercialization status							
Today	🟩	🟩	🟩	🟧 **Availability**	🟨	🟨	🟥 **Demonstration**
To 2030	🟩	🟩	🟩	🟩	🟩	🟩	🟨
Barriers today							
Vehicle	🟩	🟩	🟩	🟧 **Availability**	🟨	🟨	🟥 **Availability**
Fuel	🟩	🟩	🟠 **Feedstock, Availability**	🟠 **Infrastructure**	🟩	🟨 **Feedstock**	🟠 **Fuel Cost**
Environmental considerations							
Criteria air pollutants	🟥	🟧 **-20%**	🟧 **No Diesel PM**	🟩 **Zero Tailpipe**	🟨 **-90%**	🟨 **-90%**	🟩 **Zero Tailpipe**
Air toxics	🟥	🟧	🟠	🟩	🟨	🟨	🟩
GHG emission reductions	🟥	🟧 **-20%**	🟨 **-50 to -70%**	🟩 **-80 to -100%**	🟧 **-20%**	🟨 **-60+%**	🟠 **-50%**
Policy alignment							
To 2030	🟧	🟧	🟨	🟩	🟨	🟨	🟩
To 2050	🟥	🟥	🟠	🟩	🟠	🟠	🟩
Cost considerations							
Today	🟠	🟠	🟠	🟠	🟨	🟨	🟥
In 2030	🟠	🟠	🟨	🟩	🟨	🟨	🟧
Infrastructure	🟩	🟩	🟠	🟠	🟩	🟩	🟥

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Part 1:

Emission Impacts Scenario Analysis

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Abbreviations and Acronyms

BEV	battery electric vehicle
CAISO	California Independent System Operator
CARB	California Air Resources Board
CEC	California Energy Commission
CNG	compressed natural gas
CO_2	carbon dioxide
CO_2E	carbon dioxide equivalent
CPUC	California Public Utilities Commission
DGE	diesel gallon equivalent
EER	energy economy ratio
EMFAC	Emissions Factors Model
g/bhp-hr	grams per brake horsepower hour
gCO_2/megajoule	grams of CO2 per megajoule
g/kWh	grams per kilowatt hour
GHG	greenhouse gas
GVWR	gross vehicle weight rating
HD	heavy-duty
IDLEX	idle exhaust emissions
IPM	Integrated Planning Model
IRP	Integrated Resource Plan
kWh	kilowatt-hour
lbs	pounds
LCFS	Low Carbon Fuel Standard
MD	medium-duty
MD/HD	medium- and heavy-duty
MMBtu	million British thermal units
MMT	million metric tonnes
MWh	megawatt hour
NGV	natural gas vehicle
NOx	nitrogen oxides
NRDC	Natural Resources Defense Council
O_3	ozone
PM	particulate matter
PM10	particulate matter less than 10 microns
PM2.5	particulate matter less than 2.5 microns
RNG	renewable natural gas
RUNEX	running exhaust emissions
SCAQMD	South Coast Air Quality Management District
SOx	sulfur oxides
STREX	start exhaust tailpipe emissions
UCS	Union of Concerned Scientists
VMT	vehicle miles traveled
ZEB	zero emission buses
ZEV	zero emission vehicle

I. Purpose

The purpose of the emission impacts scenario analysis is to determine if alternative fuels and electrification in the MD and HD sectors can meet California's near- and long-term policy objectives. The fuels included in the scenario analysis included biodiesel and renewable diesel, natural gas (both fossil and renewable), and electricity. (Hydrogen fuel was included in the Total Cost of Ownership analysis, but due to ongoing projected high costs for vehicles and infrastructure and limitations on data, hydrogen-fueled vehicles were not carried forward into the scenario analysis or the economic analysis.)

The scenarios presented are summarized here and described in more detail later in the report:

1. **Current Policies (baseline)**. The Current Policies scenario includes currently adopted policies (state and federal laws, regulations, and legislative actions adopted as of December 2017), and the Sustainable Freight Action Plan. Renewable diesel and biodiesel are assumed to reach up to 1.5 billion gallons annually. The Current Policies scenario provides the baseline against which the remaining scenarios are compared.
2. **Diesel**. The Diesel scenario examines how close current fuels and infrastructure could bring California to its 2030 and 2050 targets. It adds low NOx diesel engines starting in 2024, and additional diesel fuel economy improvements post-2027, to the suite of policies contained in the baseline. These changes are also carried over into each of the remaining scenarios.
3. **Electricity**. The Electricity scenario attempts to meet 2030 and 2050 GHG and NOx emission targets with an emphasis on greater penetration of electric trucks and buses relative to the Natural Gas and Diesel scenarios.
4. **Natural Gas**. The Natural Gas scenario attempts to meet 2030 and 2050 targets with an emphasis on greater penetration of natural gas trucks and buses relative to the Electricity and scenarios.
5. **Electricity Max**. The Electricity Max scenario is intended to illustrate the upper limit of new MD and HD electrification in helping to meet the 2031 NOx target and in achieving additional GHG reductions. This scenario assumes that 100 percent of MD and HD sales are electric starting in 2024.

This report is divided into the following sections:

- Methodology
- Results
- Conclusions

II. Methodology

1. Emission Goals

Assembly Bill 32, signed by Governor Schwarzenegger in 2006, put in place a program to return California to 1990 GHG emission levels by 2020, a reduction of approximately 15% below emissions expected under a business-as-usual scenario. In addition, Governor Schwarzenegger's Executive Order S-3-05 called for all sectors to reduce GHGs by 80% from 1990 levels by 2050. Senate Bill 32, signed by Governor Brown in 2016, established a 2030 GHG reduction target of 40% below 1990 levels. The California Greenhouse Gas Inventory for

1990 reported emissions from HD trucks and buses[1] to be 29.03 million metric tonnes (MMT) of CO_2 equivalent (CO_2e) on a tailpipe basis.[2] To account for lifecycle emissions, ICF assumed tailpipe emissions accounted for approximately 75% of lifecycle emissions (derived from CA-GREET 3.0[3]). The resulting GHG targets for this analysis are listed in Table II-1.

Table II-1: Greenhouse Gas Targets

GHG Target	Million Tonnes CO_2e
1990 Levels	38.71
2020 Target (20% below 1990 levels)	30.97
2030 Target (40% below 1990 levels)	23.23
2050 Target (80% below 1990 levels)	7.74

The federal government sets National Ambient Air Quality Standards for six different criteria pollutants: carbon monoxide, lead, nitrogen dioxide, particulate matter (PM) less than 10 microns in diameter and 2.5 microns in diameter (PM10 and PM 2.5), ozone, and sulfur oxides (SOx). The South Coast Air Quality Management District (SCAQMD) and Valley Air District are currently in extreme non-attainment of the eight-hour ozone standard, and in non-attainment for the 24-hour PM2.5 standard. Between ozone and PM2.5, the ozone standard is the main driver of regulatory policies and plans because the reductions required to meet the 2023 and 2031 standards are so dramatic. SCAQMD and the Valley Air District are planning to achieve significant ozone and PM2.5 reductions through reductions in NOx emissions. According to the California Air Resources Board (CARB), an 80% reduction in truck and bus NOx tailpipe emissions is required from 2019 levels by 2031 to meet the national ambient air quality standards for ozone in the South Coast Air Basin.[4] The NOx emissions target for this analysis is based on this calculation, as shown in Table II-2.

Table II-2: NOx Tailpipe Emissions Target

NOx Target	Thousand Metric Tonnes NOx/year
2019 Levels	103
2031 Current Policies	52
2031 Target (80% below 2019 levels)	21

2. EMFAC

The baseline data used for this analysis came from CARB's Emission Factors (EMFAC) model. This model was developed for air quality planning purposes to calculate statewide or regional tailpipe emissions.[5] EMFAC2017 includes the most current data on California's car and truck fleets and travel activity. EMFAC2017 used socio-econometric regression model forecasting methods to predict new sales and vehicle miles travelled growth trends to 2050. The data reflect

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[1] This inventory category includes all MD and HD vehicles considered in this analysis.

[2] CARB, 2007

[3] CARB, 2019a

[4] CARB, 2019b

[5] CARB, 2017a

state and federal laws, regulations, and legislative actions that were adopted as of December 2017. More detail for the assumptions that went into the forecasts can be found in the EMFAC2017 technical documentation.[6]

EMFAC categorizes vehicles based on a unique set of criteria. ICF reassigned the EMFAC vehicle class categorizations in Table II-3 to the more common truck classifications used in regulations. The EMFAC category, description, and corresponding truck classification are shown in Table II-3.

Table II-3: EMFAC Vehicle Categorization

EMFAC2011 Veh and Tech	Description	Class
LHD1	light-HD trucks (GVWR 8,501-10,000 lbs)	Class 2b
LHD2	light-HD trucks (GVWR 10,001-14,000 lbs)	Class 3
T6 Ag	medium-HD diesel agriculture truck	Class 6 regional
T6 CAIRP heavy	medium-HD Diesel CA International Registration Plan truck with GVWR>26,000 lbs	Class 8 long haul
T6 CAIRP small	medium-HD Diesel CA International Registration Plan truck with GVWR<=26,000 lbs	Class 6 regional
T6 in-state construction heavy	medium-HD Diesel in-state construction truck with GVWR>26,000 lbs	Class 6 urban
T6 in-state construction small	medium-HD diesel in-state construction truck with GVWR<=26000 lbs	Class 8 short haul
T6 in-state heavy	medium-HD diesel in-state truck with GVWR>26000 lbs	Class 8 long haul
T6 in-state small	medium-HD diesel in-state truck with GVWR<=26000 lbs	Class 6 regional
T6 OOS heavy	medium-HD diesel out-of-state truck with GVWR>26000 lbs	Class 8 long haul
T6 OOS small	medium-HD diesel out-of-state truck with GVWR<=26000 lbs	Class 6 regional
T6 public	medium-HD diesel public fleet truck	Class 4-5
T6 utility	medium-HD diesel utility fleet truck	Class 4-5
T6TS	medium-HD gasoline truck	Class 4-5
T7 Ag	heavy-HD diesel agriculture truck	Class 8 short haul
T7 CAIRP	heavy-HD diesel CA International Registration Plan truck	Class 8 long haul
T7 CAIRP construction	heavy-HD diesel CA International Registration Plan Construction truck	Class 8 short haul
T7 NNOOS	heavy-HD diesel non-neighboring out-of-state truck	Class 8 long haul
T7 NOOS	heavy-HD diesel neighboring out-of-state truck	Class 8 long haul
T7 other port	heavy-HD diesel drayage truck at other facilities	drayage
T7 POAK	heavy-HD diesel drayage truck in Bay Area	drayage
T7 POLA	heavy-HD diesel drayage truck near South Coast	drayage
T7 public	heavy-HD diesel public fleet truck	Class 8 short haul
T7 single	heavy-HD diesel single unit truck	Class 8 short haul

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[6] CARB, 2017b

EMFAC2011 Veh and Tech	Description	Class
T7 single construction	heavy-HD diesel single unit construction truck	Class 8 short haul
T7 SWCV	heavy-HD diesel solid waste collection truck	Class 8 short haul
T7 tractor	heavy-HD diesel tractor truck	Class 8 short haul
T7 tractor construction	heavy-HD diesel tractor construction truck	Class 8 short haul
T7 utility	heavy-HD diesel utility fleet truck	Class 8 short haul
T7IS	heavy-HD gasoline truck	Class 8 short haul
PTO	power take off	Class 4-5
SBUS	school buses	buses
UBUS	urban buses	buses
Motor coach	motor coach	buses
Other bus	other buses	buses
All other buses	all other buses	buses

3. Emission Factors

ICF developed upstream and tailpipe emission factors for criteria pollutant emissions including NOx and PM. Upstream emissions included all the emissions needed to produce and/or process the feedstock and fuel prior to onboard vehicle emissions from fuel use. For example, upstream emissions for gasoline and diesel include crude oil extraction, pipeline/tanker/rail transport to California, and refining of crude oil to gasoline or diesel. ICF further broke down the upstream emissions between in-state and out-of-state emissions.

For lifecycle GHG emission factors, ICF utilized the values for liquid and gaseous fuels shown in Table II-4.

Table II-4. Liquid and Gaseous Fuel Carbon Intensities

Fuel	Carbon Intensity (gCO2e/MJ)
Gasoline	97.74
Diesel	100.45
Renewable Diesel/Biodiesel	35
Fossil Natural Gas	79.21
RNG	28.55

The gasoline, diesel, and fossil natural gas carbon intensities are taken from the Low Carbon Fuel Standard) LCFS regulation.[7] The renewable diesel and biodiesel carbon intensity is based on ICF's best estimate of a representative value from submitted and approved carbon intensities within the regulation. For RNG, ICF developed an in-state landfill gas carbon intensity. For long-term LCFS implications, there is an uncertain future on the extremely low carbon intensities

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[7] CARB, 2019c

being approved for animal manure and other waste pathways. As CARB moves to increase the stringency of regulations to reduce emissions from sources covered under SB 1383, the long-term potential of extremely low carbon intensities is unknown. Once CARB sets emissions reduction regulations for these waste feedstocks, the carbon intensities for those pathways will revert their carbon intensities closer to the existing landfill gas pathways. ICF chose to develop an in-state factor since the focus on RNG volumes used in this analysis is on in-state waste feedstocks, as is discussed further in Section 4.2.

The following sections detail the development of the emission factors used for the modeling, including upstream (in-state and out-of-state), for all fuels and electricity for 2019, 2030, and 2050.

3.1 Upstream – In-State/Out-of-State

The upstream emission factors from feedstock and fuel production were taken from the CA-GREET3.0 Model.[8] The emission factors were divided into in-state and out-of-state emissions in order to fully understand the California impacts of NOx and PM2.5 emissions. The in-state versus out-of-state assumptions for feedstock production and fuel production are listed in Table II-5 and Table II-6, respectively. The CA-GREET3.0 Model-derived emission factors and assumed feedstocks are listed in Table II-7. The upstream emissions are assumed to remain constant for all years in the analysis.

Table II-5: Feedstock Production Upstream Emissions Distribution

Percent of Emissions Assigned to In-State vs. Out-of-State	Upstream In-State - Feedstock	Upstream Out-of-State - Feedstock	Source
Gasoline	27%	73%	LCFS crude oil life cycle assessment (2017)[9]
Diesel	27%	73%	LCFS crude oil life cycle assessment (2017)[10]
Renewable Diesel	12%	88%	LCFS Attachment F, Table F-2[11]
Biodiesel	24%	76%	LCFS Attachment F, Table F-2[12]
Fossil Natural Gas	10%	90%	California Energy Commission[13]
Renewable Natural Gas	33%	67%	LCFS Attachment F, Table F-2[14]

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[8] CARB, 2019a
[9] CARB, 2019d
[10] Ibid
[11] CARB, 2019e
[12] Ibid
[13] CEC, 2019a
[14] CARB, 2019e

Table II-6: Fuel Production Upstream Emissions Distribution

Percent of Emissions Assigned to In-state vs. Out-of-State	Fuel Production - In-State	Fuel Production - Out-of-State	Source/Assumption
Gasoline	100%	0%	Assumption[15]
Diesel	100%	0%	Assumption[16]
Renewable Diesel	12%	88%	LCFS Attachment F, Table F-2[17]
Biodiesel	24%	76%	LCFS Attachment F, Table F-2[18]
Fossil Natural Gas	100%	0%	Assumption[19]
Renewable Natural Gas	100%	0%	LCFS Attachment F, Table F-2[20]

Table II-7: Upstream Emissions [g/mile]

Fuel Type	NOx In-State	NOx Out-of-State	PM2.5 In-State	PM2.5 Out-of-State
Low Level Ethanol Blend with Gasoline (E10)	0.171	0.067	0.010	0.004
Diesel	0.089	0.068	0.005	0.003
Renewable Diesel (Tallow)	0.080	0.586	0.006	0.044
Biodiesel (Soybean)	0.234	0.074	0.005	0.015
Renewable Natural Gas (Landfill Gas)	0.169	0.533	0.013	0.017
Fossil Natural Gas	0.0481	0.235	0.004	0.002

The CA-GREET3.0 transportation and distribution assumptions were adjusted to reflect a more accurate emissions factor for each fuel category. For the out-of-state portion, the U.S. average electricity grid mix was selected with a 2,000-mile transportation distance. For the in-state portion, the California eGRID electricity mix was selected with a 500-mile transportation distance.

3.1.1 Upstream Electricity Emissions

Similarly, upstream emissions for electricity generation were divided into in-state versus out-of-state based on the California Energy Commission (CEC) reported percentages of in-state generation in 2017. The distribution by fuel type is reported in Table II-8. For natural gas, the percentage breakdowns were further adjusted to account for the location of production. Ninety percent of the total natural gas used in-state is produced out-of-state (Table II-5); therefore, 90% of the feedstock emission factors were assigned to out-of-state.

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[15] Assuming 100% of refined product used in transportation vehicles is produced in state
[16] Ibid.
[17] CARB, 2019e
[18] Ibid
[19] Production in this case equals compression to compressed natural gas (CNG); 100% of compression to CNG occurs in state, 0% CNG is trucked into CA; same value as RNG.
[20] CARB, 2019e

Table II-8: Electricity Generation Upstream Emissions Distribution for 2019[21]

Fuel Type	Percent In-State	Percent Out-of-State
Coal	3%	97%
Large Hydro	86%	14%
Natural Gas[22]	91%	9%
Nuclear	68%	32%
Residual Oil	100%	0%
Other (Petroleum Coke/Waste Heat)	100%	0%
Renewables	72%	28%
Biomass	85%	15%
Geothermal	92%	8%
Small Hydro	82%	18%
Solar	82%	18%
Wind	47%	53%

The assumed resource mix for electricity generation in 2019, 2030, and 2050 is listed in Table II-9. It should be noted that current California policy in SB100 calls for carbon-free electricity by 2045. Under that policy, electricity use in 2045 and later should, on net, be zero carbon. If so, the GHG emissions factor for electric vehicle charge could be zero. In the following tables, the GHG emission factor presented is calculated and based solely on the grid mix and does not assume grid carbon neutrality.

The generation mix for 2019 is based on CARB's 2019 proposed LCFS average electricity pathway. The value for hydro power was modified to reflect the 10-year average of 9.5% to provide a more conservative grid mix. The balance was assumed to be natural gas.

The generation mix for 2030 is based on the latest California Public Utility Commission (CPUC) California Independent System Operator (CAISO)-wide Integrated Resource Plan (IRP) projections for 2030.

The generation mix for 2050 is based on ICF's Integrated Planning Model (IPM)[23] modeling conducted for the Natural Resources Defense Council (NRDC).[24] Biomass originally comprised 1.4% of the generation mix under ICF's IPM modeling. However, in every scenario in E3's March 2019 report to the CEC,[25] biomass is always unchanged. This suggests that with or without increased load for electric vehicle demand, biomass emissions are predicted to remain unchanged. In a long-term marginal emissions analysis, biomass emissions would not be attributed to electric vehicle adoption. As a result, biomass was removed from the 2050 generation mix for this analysis and replaced with natural gas.

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[21] CEC, 2019b

[22] Assumed 10% of feedstock was in-state, 90% out-of-state

[23] ICF's Integrated Planning Model (IPM) integrates wholesale power, system reliability, environmental constraints, fuel choice, transmission, capacity expansion, and operational elements in a linear optimization framework.

[24] ICF, under contract with NRDC, has performed IPM modeling as part of multiple other projects. The results from those previous analyses were supplied by NRDC and utilized in this report

[25] CEC, 2019c

Table II-9: Assumed Resource Mix for Electricity Generation

Generation Mix	2019 Grid Mix[26]	2030 Grid Mix (CPUC CAISO-wide IRP)[27]	2050 Grid Mix (ICF modeling for NRDC with no biomass, NGCC-only)[28]
Residual Oil	0%	0%	0%
Natural Gas	51%	34%	8%
Coal	4%	0%	0%
Biomass	2%	1%	0%
Nuclear	9%	2%	0%
Hydro	10%	11%	11%
Geothermal	4%	9%	8%
Wind	9%	11%	43%
Solar PV	10%	33%	29%

For NOx and PM2.5 emissions, feedstock and fuel emissions rates by power plant type were sourced from CA-GREET3.0. The GREET NOx emission factors for large boiler and combustion turbine natural gas power plants were adjusted to reflect emission rates of California power plants as reported by the U.S. Environmental Protection Agency (USEPA) Clean Air Markets Division database for calendar year 2015. Using these values, the GREET3.0 default of 74.5 g NOx/MMBtu for the average natural gas plant in California was corrected to 57.5 g/MMBtu.

By 2050, the assumption was made that nearly all-natural gas electric generation is from new combined cycle plants. As a result, natural gas combined cycle emission rates for natural gas power generation were used for 2050 in this analysis.

The emission factors for feedstock and fuel for 2019, 2030, and 2050 are listed in Table II-10 A linear ramp was used for emissions factors in the interim years. Table II-11 and Table II-12 reflect the emissions attributed to in-state and out-of-state based on the distribution presented in Table II-8.

Table II-10: NOx, PM2.5, and GHG Emission Factors for Electricity Generation for Feedstock and Fuel

	NOx (lbs/MWh)			PM2.5 (lbs/MWh)			GHG (lbs/MWh)			GHG (gCO2e /MJ)
	Feedstock	Fuel	Total	Feedstock	Fuel	Total	Feedstock	Fuel	Total	
2019 CEC Grid Mix (avg hydro)	0.39	0.44	0.83	0.01	0.06	0.064	128	612	739	93.11
2030 CPUC CAISO-wide IRP	0.24	0.17	0.42	0.0032	0.02	0.018	79	353	432	54.43
2050 NRDC with no biomass, NGCC-only)	0.06	0.01	0.06	0.001	0.001	0.002	18	97	115	14.50

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[26] CARB, 2019f
[27] CPUC, 2019
[28] ICF modeling for NRDC

Table II-11: Upstream - In-State Emissions From Electricity Generation [g/kWh]

Upstream- In-State	NOx (g/kWh)	PM2.5 (g/kWh)	GHG (g/kWh)
2019	0.16	0.0158	222.6
2030	0.08	0.0062	149.84
2050	0.00	0.0006	40.83

Table II-12: Upstream - Out-of-State Emissions From Electricity Generation [g/kWh]

Upstream- Out-of-State	NOx (g/kWh)	PM2.5 (g/kWh)	GHG (g/kWh)
2019	0.22	0.0135	113.2
2030	0.11	0.0021	46.25
2050	0.02	0.0003	11.42

3.2 Tailpipe

3.2.1 NOx Tailpipe Emission Factors

Diesel and 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. As a simplifying assumption, the same emission factors for tailpipe criteria pollutant emissions (NOx and PM) were used for conventional diesel, biodiesel, and renewable diesel. Recent alternative diesel requirements include the use of an additive to ensure that biodiesel does not increase NOx emissions. 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

Natural Gas Vehicles

All new natural gas vehicles are assumed to have a low-NOx natural gas engine. These engines are certified at 0.02 g/bhp-hr, which is a 90% reduction from the current diesel standards of 0.2 g/bhp-hr. In ICF’s model, the NOx emissions factors for new natural gas vehicles were assumed to be 10% of the emissions factor of the diesel vehicle it is replacing. The same tailpipe emission factors were used for conventional natural gas and RNG. Most natural gas used in vehicles is taken directly from the common carrier pipeline and the use of RNG is a paper/documentation transaction, not the use of actual RNG molecules in the engine.

Electric Vehicles

Electric vehicles were modeled to have zero tailpipe NOx emissions.

3.2.2 PM2.5 Tailpipe Emission Factors

PM emissions labeled as "tailpipe" in the scenarios account for both engine use and emissions from tires and braking.

Diesel and 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 PM2.5 used in this model include:

- RUNEX that come out of the vehicle tailpipe while traveling on the road
- 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)
- STREX that occur when starting a vehicle
- Tire wear particulate matter emissions that originate from tires as a result of wear
- Brake wear particulate matter emissions that originate from brake usage

Natural Gas Vehicles

For the scenario calculations, all new natural gas vehicles are assumed to have a low-NOx certified engine. All new natural gas vehicles were assumed to have a running exhaust emission factor of 0.0005 g/mile based on EMFAC emission factors for CNG vehicles and recent certification data for Low-NOx engines[29]. The tire and brake wear emissions factors for natural gas vehicles were assumed to be equivalent to the diesel vehicle they are replacing.

Electric Vehicles

Electric vehicles were modeled to have zero running, idling, or starting tailpipe PM2.5 emissions. The model assumed electric vehicle emissions for tire and brake wear to be 50% of diesel vehicle emissions.[30]

3.3 Summary Emission Factors

The emission factors used in the modeling are by model year, specific vehicle type, and duty cycle. Figure II-1 and Figure II-2 provide average emission factors used for various HD vehicle classes. For electricity, the emissions factors in the model for years between 2019 and 2030 and 2030 and 2050 are linearly interpolated from the emissions factors quantified for 2019, 2030, and 2050.

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[29] A 50 percent reduction in PM2.5 emissions is assumed for Low-NOx CNG engines compared to regular CNG engines based on CARB engine certification data. See certification data for low-NOx 8.9L CNG https://ww3.arb.ca.gov/msprog/onroad/cert/mdehdehdv/2016/cummins_ub_a0210629_8d9_0d02-0d01_ng.pdf and certification data for 8.9L CNG https://ww3.arb.ca.gov/msprog/onroad/cert/mdehdehdv/2015/cummins_ub_a0210616_8d9_0d20-0d01_ng.pdf

[30] ICF assumption based on the reduced tire and brake wear from regenerative breaking.

Figure II-1. NOx Emission Factory Summary (g/mile)

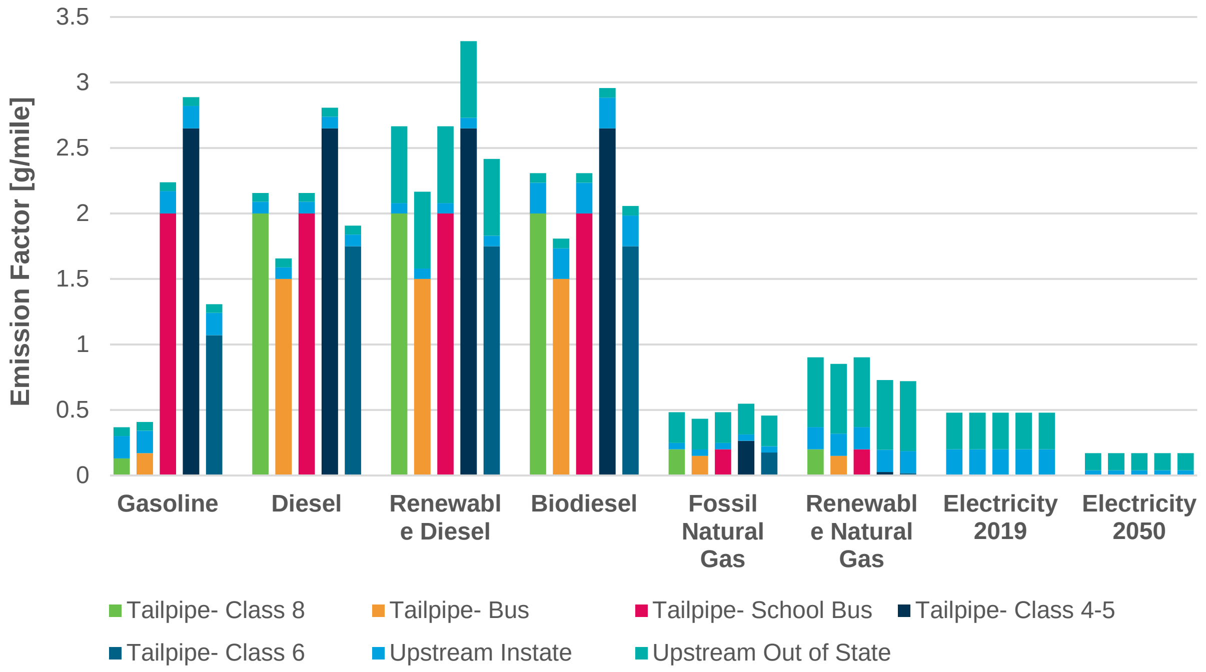
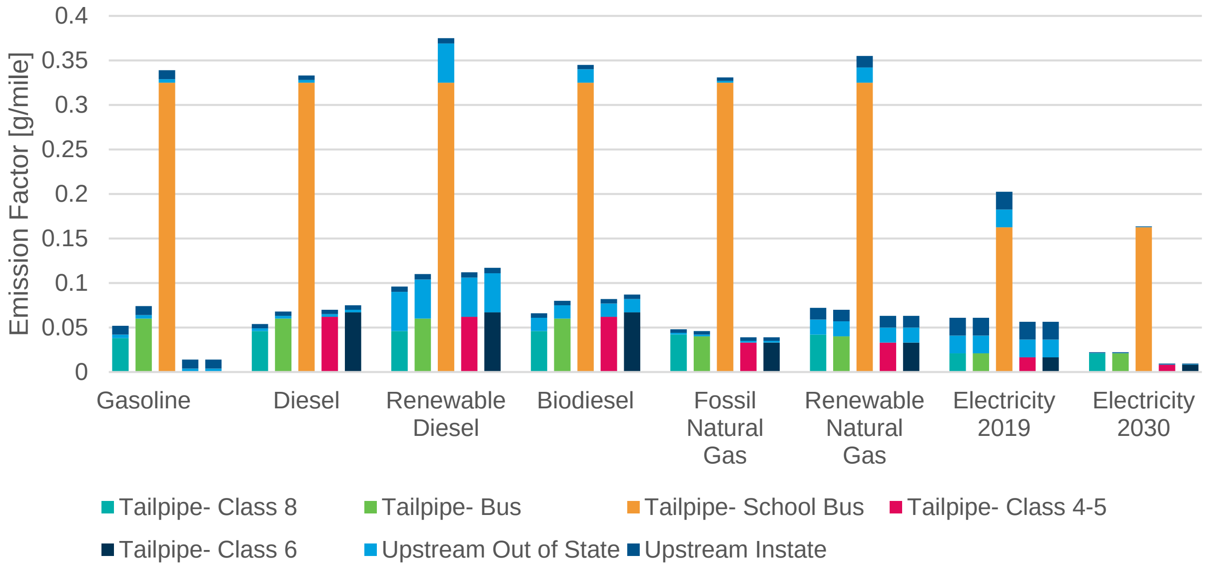
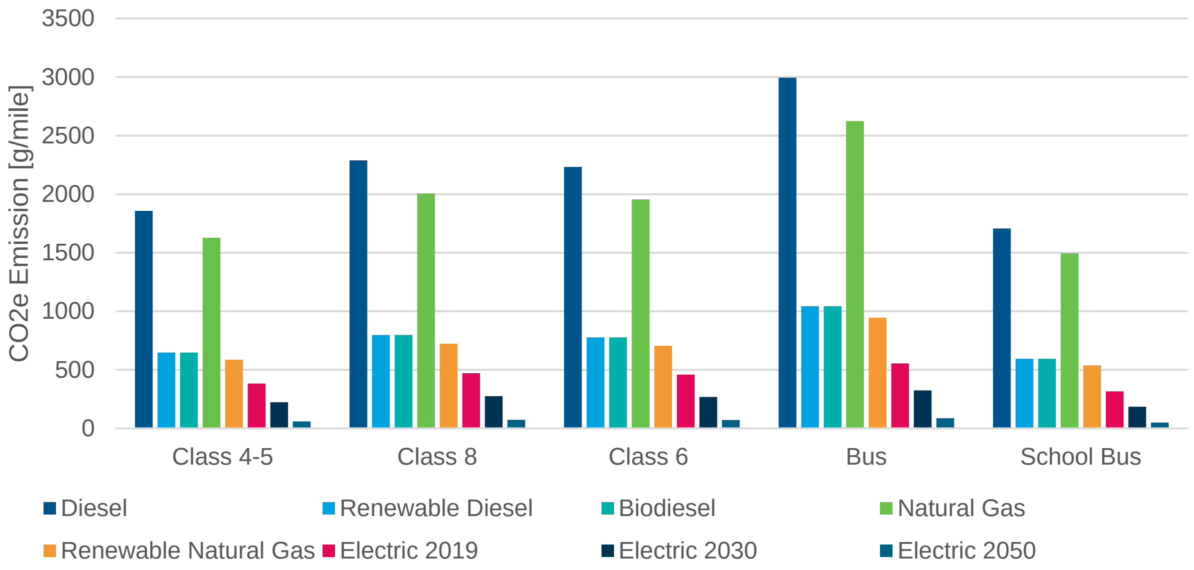


Figure II-2. PM2.5 Emission Factor Summary (g/mile)



Electric, with zero emission tailpipe emissions, has the lowest NOx emission factors, and natural gas achieves NOx reductions compared to gasoline and diesel. Also, there are less significant reductions for PM2.5 from natural gas and electric compared gasoline and diesel. The increased emissions from school buses for PM, even in the electric case, is due to emissions from tires and braking. Figure II-3 shows the GHG emission factors for some select vehicle categories.[31]

Figure II-3. GHG Emission Factor Summary (g/mile)



Electric has the greatest potential for per mile GHG emission reductions compared to diesel. RNG has the potential to achieve slightly more emission reductions than renewable diesel and biodiesel and less than electricity, especially in 2050.

4. Alternative Fuels

4.1 Biofuels

The CEC[32] and LCFS Quarterly Report summaries[33] showed that the blend of ethanol in the gasoline pool has remained constant at about 10% since 2010. Considering the relatively small consumption of gasoline in the MD/HD sector, ICF assumed a continued 10% ethanol blend in the gasoline pool to 2050.

California's Clean Fuel Future[34] modeled compliance scenarios for the LCFS to 2030. ICF used the volumes reported in California's Clean Fuel Future High Performance scenario as the maximum available biodiesel and renewable diesel for consumption in the model. ICF chose to use the high-performance scenario and allocate the entire hydrotreated category to renewable diesel to present the full potential of what existing diesel vehicles can achieve. The combined biodiesel and renewable diesel volumes for 2019, 2025, and 2030 are 180, 880, and 1,500 million DGE per year respectively. ICF used these volumes as the maximum potential of liquid biofuel volumes in all scenarios, based on the assumption that LCFS compliance is included in

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[31] EER values to convert between g/MJ to g/mile for Class 4/5, Class 6, Class 8, and buses are 4.2, 5, 5 and 5, respectively. A more detailed discussion on the EER values can be found in the Technology Assessment.

[32] CEC, 2019d

[33] CARB, 2019g

[34] Malins, 2018

all scenarios and maximizing the use of drop-in liquid biofuels is necessary for LCFS compliance through 2030.

4.2 RNG

ICF performed a California resource assessment for RNG production potential from various feedstocks in 2017.[35] The analysis used the RNG production potential from waste feedstocks because they yield the highest potential LCFS credit value and result in the greatest potential for the product RNG to be used in the transportation sector. The waste feedstocks of animal manure, landfill gas, municipal solid waste, and wastewater treatment plant result in an RNG potential and maximum availability of 750 million DGE to the transportation sector. While RNG can and likely will be produced from non-waste feedstocks in the 2030 timeframe, as shown in the ICF resource assessment, the higher carbon intensity of these fuels will make them unlikely fuels for the LCFS and they will likely be used in other sectors such as building heating, industrial, and electricity generation. ICF used the 750 million DGE value as the maximum potential RNG in all the scenarios.

5. Scenarios

There are 10 basic strategies that are bundled and adjusted to make up the scenarios that are presented within this report. Appendix A – Additional Results includes detailed figures on emissions, fuel consumption, and other results for the scenarios presented. Most strategies assume for modeling purposes that existing or proposed regulations or strategies are deployed on a specific number of vehicles. The scenarios in this report are illustrative, and not necessarily dependent on a particular regulation listed below, because incentives and voluntary actions might partially replace or enhance a regulation.

The strategies that were included in the analysis are listed below. Existing policies and regulations are identified as such. Each scenario specifies which strategies are included, and how they were adjusted. Table II-17 , which follows the strategy list, provides a summary of which strategies were included in each scenario.

1. **Phase 2 GHG Standards[36](Existing)**
   New requirements for new Class 2 through Class 8 vehicles. Requirements phase in between 2018 and 2027.
2. **Senate Bill 1 (Truck and Bus Regulation - Existing)**
   SB-1 requires the Department of Motor Vehicles to verify that MD and HD vehicles are compliant or exempt from CARB’s Truck and Bus Regulation.[37] The regulation phases in a requirement that diesel vehicles with a gross vehicle weight rating (GVWR) greater than 14,000 lbs. that operate in California have a model year 2010 engine. The model assumes full compliance by January 1, 2023.
3. **Innovative Clean Transit[38] (Existing)**
   The Innovative Clean Transit regulation sets a statewide goal for public transit agencies to gradually transition to 100 percent zero-emission bus (ZEB) fleets by 2040. The

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[35] ICF, 2017
[36] USEPA, 2016
[37] CARB, 2010
[38] CARB, 2017c

regulation mandates the percentage of annual new bus purchases that must be zero-emission. Agencies must follow a phased schedule from 2023 to 2029, as shown in Table II-13. For modeling purposes, ICF assumed that this regulation applied to all vehicles in the Urban Bus EMFAC category. 27% of these vehicles were assumed to be in small transit agencies, while the remaining 73% were in large transit agencies. ICF assumed that sales in the interim years follow a linear trajectory between the regulation years. All new ZEB sales were assumed to be electric.

Table II-13: Innovative Clean Transit Percentage of Annual ZEB New Bus Sales

Percent of New Bus Purchases That Must Be ZEBs	2023	2026	2029
Small Transit Agencies	25%	50%	100%
Large Transit Agencies	–	25%	100%

4. **Sustainable Freight Action Plan[39] (Existing)**
The Sustainable Freight Action Plan is a long-term plan for California’s future freight transport system. It targets improving freight system efficiency by 25% by 2030. ICF modeled achieving this target by assuming a 25% reduction in fuel consumption from in-state freight trucks by 2030. The annual reduction in fuel consumption is a linear interpolation for the years between 2019 and 2030. The reduction remains constant at 25% from 2030 to 2050.
5. **San Pedro Bay Ports Clean Air Action Plan (Existing)**
The Clean Air Action Plan outlines strategies to reduce pollution from port-related sources, including on-road drayage trucks. The plan requires any new truck registered in the Port Drayage Truck Registry (PDTR) after Oct 1, 2018 to be model 2014 or newer. All existing trucks in the registry can continue to operate yet must comply with CARB’s Truck and Bus regulation. ICF modeled this regulation by assuming model year 2014 emission factors for all older model year South Coast Drayage Trucks (EMFAC category POLA).
6. **Implementing Low NOx Diesel Engines**
The model assumes that by 2024 new diesel vehicles will have an emission factor of 0.05 g NOx/bhp-hr. This was modeled as a 75% reduction from Current Policies emission factors in 2024. For calendar 2027 and beyond, the model assumes new diesel vehicles will have an emission factor of 0.02 g NOx/ bhp-hr, modeled as a 90% reduction in 2027 as shown in Table II-14 below.

Table II-14: Low NOx Diesel Engine Emission Factors

Engine Model Years	NOx Emissions Factor (g NOx/bhp-hr)
Current Policies (all model years)	0.2
2024	0.05
2027	0.02

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[39] CARB, 2016

7. **Increased efficiency and GHG improvements beyond Phase 2 GHG Standards**
   By 2050, fuel economy is modeled as a 10% improvement from the EMFAC assumptions.
8. **Advanced Technology Deployment**[40]
   Advanced technology deployment aims to accelerate alternative fuel truck deployments by steadily increasing new vehicle sales, which could be achieved through manufacturer requirements, fleet purchase requirements, incentives, or other policy mechanisms. The assumed sales percentage are shown in Table II-15. Changes to these percentages for individual scenarios are described in Section 5.

Table II-15: Advanced Clean Trucks ZEV Sales Percentage Requirement

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%
2035*	25%	100%	25%
2050*	55%	100%	55%

Assumed extension based on previous rate of increase. Sales percentages for model year 2024 through 2030 are based on an early draft of CARB's proposed Advanced Clean Truck Rule.

9. **Zero-Emission Airport Shuttle Regulation**[41]
   This existing regulation requires California's 13 largest airports to transition their shuttle operations to 100% ZEVs by 2035, including public and private fleets. The Green Car Congress reports that this regulation would apply to approximately 1,000 airport shuttles. To model this regulation, ICF replaced 1,000 vehicles in the Other Bus EMFAC category with electric buses.

Table II-16: Zero-Emission Airport Shuttle Regulation Fleet EV Percentage

Airport Shuttle	Percent of Fleet
2028	33%
2035	100%

10. **Advanced Technology Deployment for Out-of-State Trucks**
    This strategy assumes that beginning in 2035 a percentage of new sales of out-of-state trucks that operate in California will be alternative fueled. The model assumes that by 2050 50% of out-of-state new truck sales will be alternative fueled.

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[40] CARB, 2019h
[41] Green Car Congress. 2019

Table II-17 shows a summary of the strategies included when modeling each of the five (5) scenarios presented in this report. The next section outlines how each of the strategies were included or modified to meet the 2030 and/or 2050 goals.

Table II-17: Scenario Summary

	Current Policies	Diesel	Natural Gas	BEV	Electricity Max (bounding case)
Phase 2 GHG Standards	✓	✓	✓	✓	✓
Senate Bill 1 (Truck and Bus Regulation)	✓	✓	✓	✓	✓
Innovative Clean Transit	✓	✓	✓+	✓+	✓+
Sustainable Freight Action Plan	✓	✓	✓	✓	✓
San Pedro Bay Ports Clean Air Action Plan	✓	✓	✓	✓	✓
Implementing Low NOx Diesel Engines		✓	✓	✓	✓
Further Tightening of Phase 2 GHG Standards		✓	✓+	✓+	✓+
Advanced Technology Deployment			✓NG+	✓EV+	✓EV+
Zero-Emission Airport Shuttle Regulation			✓+	✓+	✓+
Out-of-State Truck Requirement			✓NG	✓EV	✓EV+

✓ Strategy included in scenario
+ Adjustments were made to make the strategy more aggressive.
EV: Vehicle sales were assumed to be electric.
NG: Vehicle sales were assumed to be natural gas.
Mix: Vehicle sales were a mix of electric and natural gas vehicles.

5.1 Scenario Details

The following sections provide detail on the intended purpose of each scenario, the assumptions included, and how any of the strategies were modified to meet the 2030 and 2050 policy goals. If identified as “None” the strategy, as identified in the section above, was employed unchanged.

5.1.1 Current Policies Scenario

This scenario adds current policies to the EMFAC assumptions (state and federal laws, regulations, and legislative actions adopted as of December 2017). Table II-18 shows the strategies included in the Current Policies scenario.

Table II-18: Strategies Included in Current Policies Scenario

Strategies Included	Adjustments Made
Phase 2 GHG Standards	None
Senate Bill 1 (Truck and Bus Regulation)	None
Innovative Clean Transit	None
Sustainable Freight Action Plan	None
San Pedro Bay Ports Clean Air Action Plan	None

5.1.2 Diesel Scenario

The purpose of the Diesel scenario is to model additional diesel fuel economy and emission factor improvements. This illustrates how close current infrastructure could bring California to its 2030 and 2050 targets. Table II-19 shows the strategies included in the Diesel scenario.

Table II-19: Strategies Included in Diesel Scenario

Strategies Included	Adjustments Made
Phase 2 GHG Standards	None
Senate Bill 1 (Truck and Bus Regulation)	None
Innovative Clean Transit	None
Sustainable Freight Action Plan	None
San Pedro Bay Ports Clean Air Action Plan	None
Implementing Low NOx Diesel Engines	None
Further Tightening of Phase 2 GHG Standards Beyond 2027	None

5.1.3 Natural Gas Scenario

The purpose of Natural Gas scenario is to attempt to meet 2030 and 2050 targets with an emphasis on greater penetration of natural gas trucks and buses relative to the Electricity scenarios. Because the constrained availability of RNG prevented meeting the 2050 GHG targets, this scenario became a mirror to the Electricity scenario, using natural gas vehicles instead of BEVs for the Advanced Technology Deployment strategy. This scenario also assumes a portion of out-of-state trucks that operate in California would transition to alternative fuels, in this case natural gas. Table II-20 shows the strategies included in the Natural Gas scenario.

Table II-20: Strategies Included in Natural Gas Scenario

<table>
<tr><th>Strategies Included</th><th>Adjustments Made</th></tr>
<tr><td>Phase 2 GHG Standards</td><td>None</td></tr>
<tr><td>Senate Bill 1 (Truck and Bus Regulation)</td><td>None</td></tr>
<tr><td>Innovative Clean Transit</td><td>• Includes all bus EMFAC categories, rather than just urban buses. Now includes: urban bus, school bus, motor coach, other bus, all other buses.</td></tr>
<tr><td>Sustainable Freight Action Plan</td><td>None</td></tr>
<tr><td>San Pedro Bay Ports Clean Air Action Plan</td><td>None</td></tr>
<tr><td>Implementing Low NOx Diesel Engines</td><td>None</td></tr>
<tr><td>Further Tightening of Phase 2 GHG Standards Beyond 2027</td><td>• Increased fuel economy improvement to 20% by 2050
• Includes in-state and out-of-state trucks</td></tr>
<tr><td>Advanced Technology Deployment</td><td>• Assumed all new sales are natural gas vehicles
• Increased the assumed rate of natural gas vehicle sales from 2030-2050
<table>
<tr><th>Model Year</th><th>Class 2B-3</th><th>Class 4-8 Vocational</th><th>Class 7-8 Tractors</th></tr>
<tr><td>2030</td><td>15%</td><td>50%</td><td>15%</td></tr>
<tr><td>2050</td><td>100%</td><td>100%</td><td>100%</td></tr>
</table></td></tr>
<tr><td>Zero-Emission Airport Shuttle Regulation</td><td>• 100% of fleet electric by 2025, rather than 2035</td></tr>
<tr><td>Out-of-State Truck Requirement</td><td>• Assumed natural gas vehicles</td></tr>
</table>

5.1.4 Electricity Scenario

The purpose of the Electricity scenario is to attempt to meet 2030 and 2050 targets with an emphasis on greater penetration of electric trucks and buses relative to the Natural Gas and Diesel scenarios. Table II-21 shows the strategies included in the Electricity scenario.

Table II-21: Strategies Included in Electricity Scenario

<table>
<tr><th>Strategies Included</th><th>Adjustments Made</th></tr>
<tr><td>Phase 2 GHG Standards</td><td>None</td></tr>
<tr><td>Senate Bill 1 (Truck and Bus Regulation)</td><td>None</td></tr>
<tr><td>Innovative Clean Transit</td><td>Includes all bus EMFAC categories, rather than just urban buses. Now includes: urban bus, school bus, motor coach, other bus, all other buses.</td></tr>
<tr><td>Sustainable Freight Action Plan</td><td>None</td></tr>
<tr><td>San Pedro Bay Ports Clean Air Action Plan</td><td>None</td></tr>
<tr><td>Implementing Low NOx Diesel Engines</td><td>None</td></tr>
<tr><td>Further Tightening of Phase 2 GHG Standards Beyond 2027</td><td>Increased fuel economy improvement to 20% by 2050
Includes in-state and out-of-state trucks</td></tr>
<tr><td>Advanced Technology Deployment</td><td>Assumed all new sales are BEVs
Increased the assumed rate of Electricity sales from 2030-2050
<table>
<tr><th>Model Year</th><th>Class 2B-3</th><th>Class 4-8 Vocational</th><th>Class 7-8 Tractors</th></tr>
<tr><td>2030</td><td>15%</td><td>50%</td><td>15%</td></tr>
<tr><td>2050</td><td>100%</td><td>100%</td><td>100%</td></tr>
</table></td></tr>
<tr><td>Zero-Emission Airport Shuttle Regulation</td><td>100% of fleet electric by 2025, rather than 2035</td></tr>
<tr><td>Out-of-State Truck Requirement</td><td>Assumed BEVs</td></tr>
</table>

5.1.5 Electricity Max Scenario

The purpose of the Electricity Max scenario is to define an upper limit showing the potential of BEVs to help meet the 2031 NOx target and achieve additional GHG reductions. This scenario maximizes the new sales rate of adoption for BEVs in the MD/HD sector while retaining the natural vehicle turnover rate. Table II-22 shows the strategies included in the Electricity Max scenario.

Table II-22: Strategies Included in Electricity Max Scenario

<table>
<tr><th>Strategies Included</th><th>Adjustments Made</th></tr>
<tr><td>Phase 2 GHG Standards</td><td>None</td></tr>
<tr><td>Senate Bill 1 (Truck and Bus Regulation)</td><td>None</td></tr>
<tr><td>Innovative Clean Transit</td><td>• Includes all bus EMFAC categories, rather than just urban buses. Now includes: urban bus, school bus, motor coach, other bus, all other buses.</td></tr>
<tr><td>Sustainable Freight Action Plan</td><td>None</td></tr>
<tr><td>San Pedro Bay Ports Clean Air Action Plan</td><td>None</td></tr>
<tr><td>Implementing Low NOx Diesel Engines</td><td>None</td></tr>
<tr><td>Further Tightening of Phase 2 GHG Standards Beyond 2027</td><td>• Out-of-state fuel economy improvement to 20% by 2050</td></tr>
<tr><td>Advanced Technology Deployment</td><td>• Assumed all new sales are BEVs
• 100% of new sales electric vehicles by 2024<table>
<tr><th>Model Year</th><th>Class 2B-3</th><th>Class 4-8 Vocational</th><th>Class 7-8 Tractors</th></tr>
<tr><td>2024 and beyond</td><td>100%</td><td>100%</td><td>100%</td></tr>
</table></td></tr>
<tr><td>Zero-Emission Airport Shuttle Regulation</td><td>• 100% of fleet electric by 2025, rather than 2035</td></tr>
<tr><td>Out-of-State Truck Requirement</td><td>• Assumed BEVs
• Out-of-state electric vehicle sales beginning in 2020
• 100% of out-of-state vehicle sales electric vehicles by 2024</td></tr>
</table>

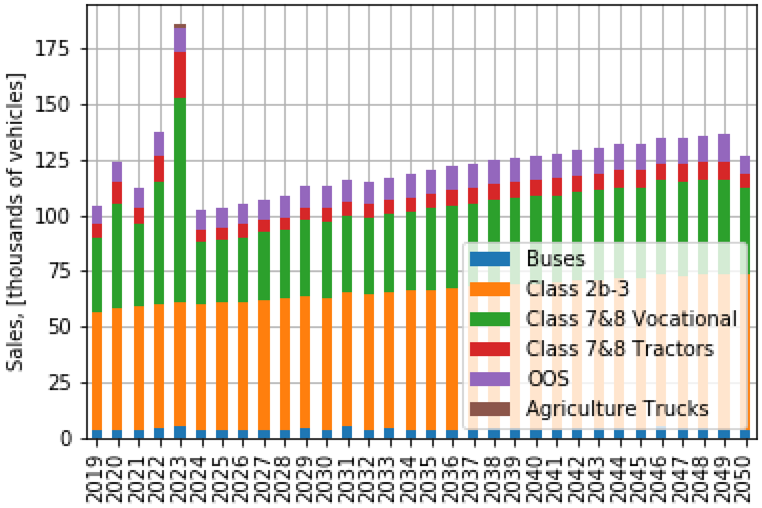
III. Results

The following section contains summarized results for each scenario including:

1. **Vehicle Profile:**
   The resulting vehicle sales and population by fuel type. The distribution of technology type varies between scenarios based on the assumptions listed previously.
2. **CO_2e Emissions:**
   The GHG emissions for each scenario are shown on a lifecycle basis.
3. **NOx Emissions:**
   For each scenario, the results include tailpipe, upstream in-state, and upstream out-of-state NOx emissions.
4. **PM2.5 Emissions:**
   For each scenario, the results include tailpipe, upstream in-state, and upstream out-of-state PM2.5 emissions.

To comply with the Truck and Bus Regulation, EMFAC assumes a significant one-time retirement of mid-life older trucks. Most of these vehicles are model year 2016 or 2017. Vehicle sales spike in calendar years 2020-2023 if all model years are considered, as shown in Figure III-1.

Figure III-1. Vehicle Sales Including All Model Years by Category



For this analysis, vehicle sales for each calendar year are defined as the sum of:

1. New model year vehicles sold in the current calendar year (e.g. model year 2020 vehicles purchased in 2020)
2. Future model year vehicles sold in the current calendar year (e.g. model year 2021 vehicles purchased in 2020)
3. Preceding model year vehicles sold in the current calendar year that exceed those sold in the previous year (e.g. model year 2019 vehicles purchased in 2020 that exceed model 2019 vehicles sold in 2019)

This small reshuffling of vehicle sales does not result in any change of overall vehicle sales, just recategorizing them to make it easier to track model year changes such as vehicle efficiency and manufacturer sales requirements.

Figure III-2 and Figure III-3 present the new vehicle sales and vehicle population of MD and HD trucks in California by vehicle category. The apparent decrease in vehicle sales in 2050 is a result of EMFAC ending at calendar year 2050. Though the fuel type varies, the number of vehicles in each category remains constant throughout the scenarios.

Figure III-2. New Vehicle Sales by Category

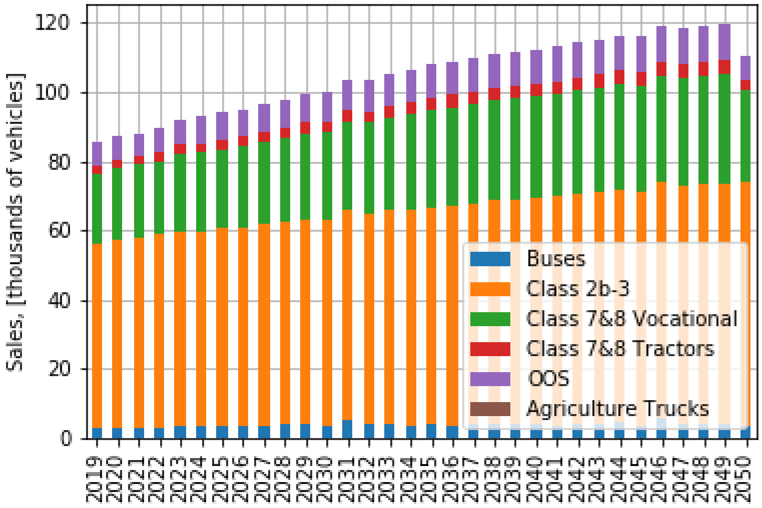
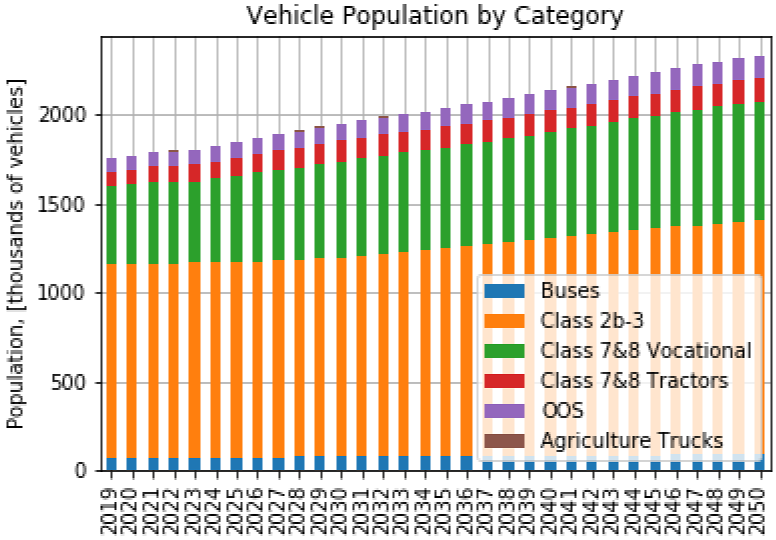


Figure III-3. Vehicle Population by Category



These figures show steady increasing sales and a steady increasing population of MD and HD vehicles in California.

1. Scenario Comparison

The following sections compare the vehicle profile and emissions results of the five modeled scenarios.

1.1 Vehicle Profile

Figure III-4 and
Figure III-5 show the results for the natural gas and BEV populations.

Figure III-4. Scenario Natural Gas Vehicle Population Comparison

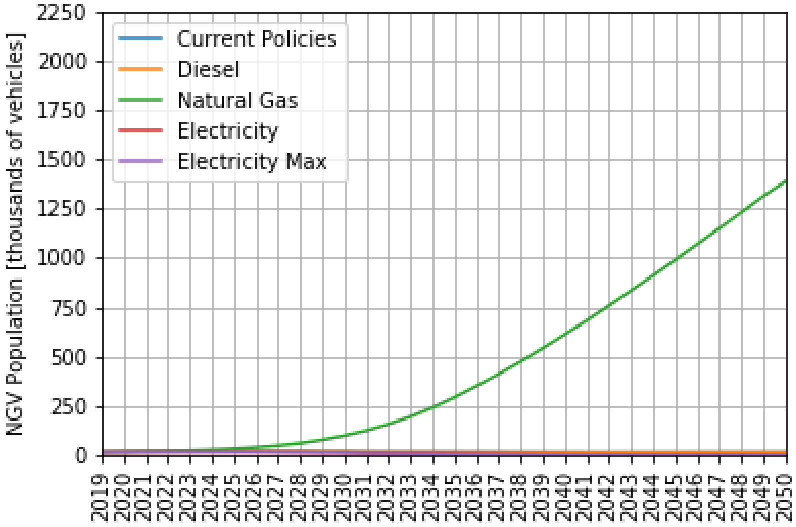


Figure III-5 Scenario BEV Population Comparison

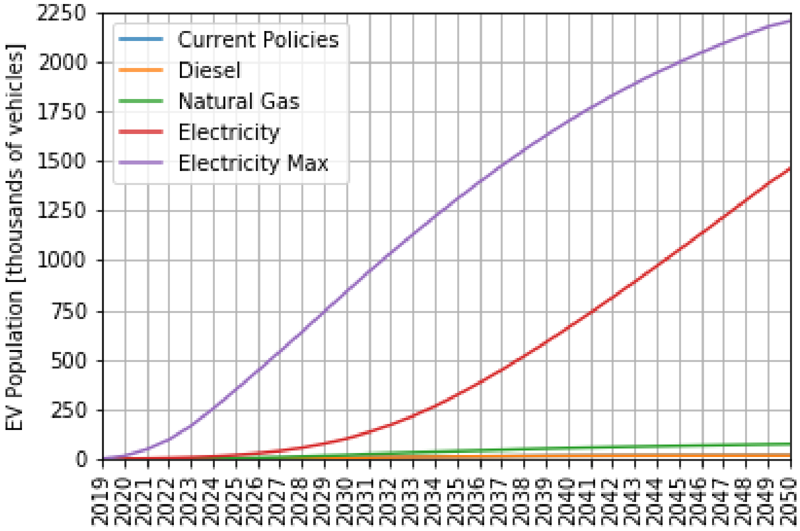


Table III-1 and Table III-2 show the detailed populations in 2030 and 2050 and percentage of the total population for the five scenarios.

Table III-1: Electric and Natural Gas Vehicle Population by Scenario [thousands of vehicles]

Scenario	Vehicle Type	2030	2050
Current Policies	Electric	5	19
	Natural Gas	18	15
Diesel	Electric	5	19
	Natural Gas	18	15
Natural Gas	Electric	20	75
	Natural Gas	99	1,387
Electricity	Electric	101	1,458
	Natural Gas	17	3
Electricity Max	Electric	838	2,201
	Natural Gas	13	1

Table III-2. Percentage of Total Population

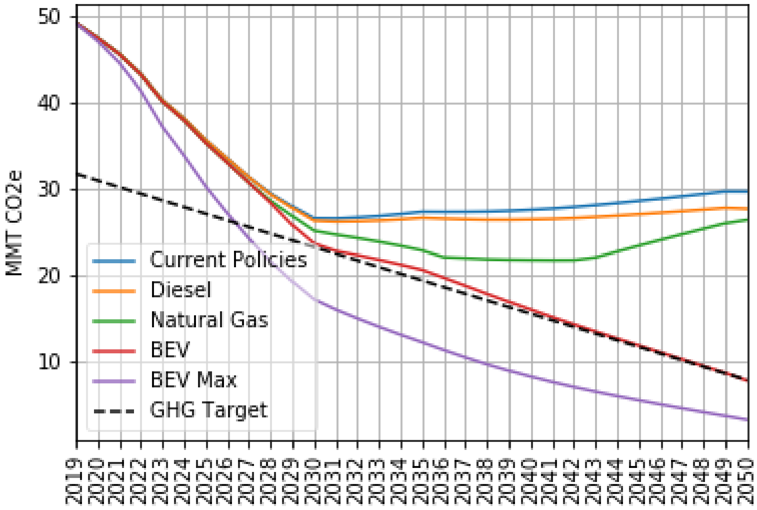
Scenario	Vehicle Type	2030	2050
Current Policies	Electric	0.27%	0.80%
	Natural Gas	0.94%	0.65%
Diesel	Electric	0.27%	0.80%
	Natural Gas	0.94%	0.65%
Natural Gas	Electric	1.01%	3.21%
	Natural Gas	5.07%	59.59%
Electricity	Electric	5.21%	62.67%
	Natural Gas	0.87%	0.13%
Electricity Max	Electric	43.05%	94.58%
	Natural Gas	0.65%	0.05%

The Electricity scenario results in more than 100,000 electric MD and HD vehicles in 2030 and more than 1.4 million in 2050. The Electricity Max scenario, which defines the upper limit of the electrification potential, with all new vehicles being BEVs after 2024, results in more than 800,000 electric MD and HD vehicles in 2030 and 2.2 million in 2050. The Natural Gas scenario results in more than 99,000 natural gas vehicles 2030 and almost 1.4 million in 2050.

1.2 CO_2e Emissions

Figure III-6 shows the GHG emission results for the five scenarios.

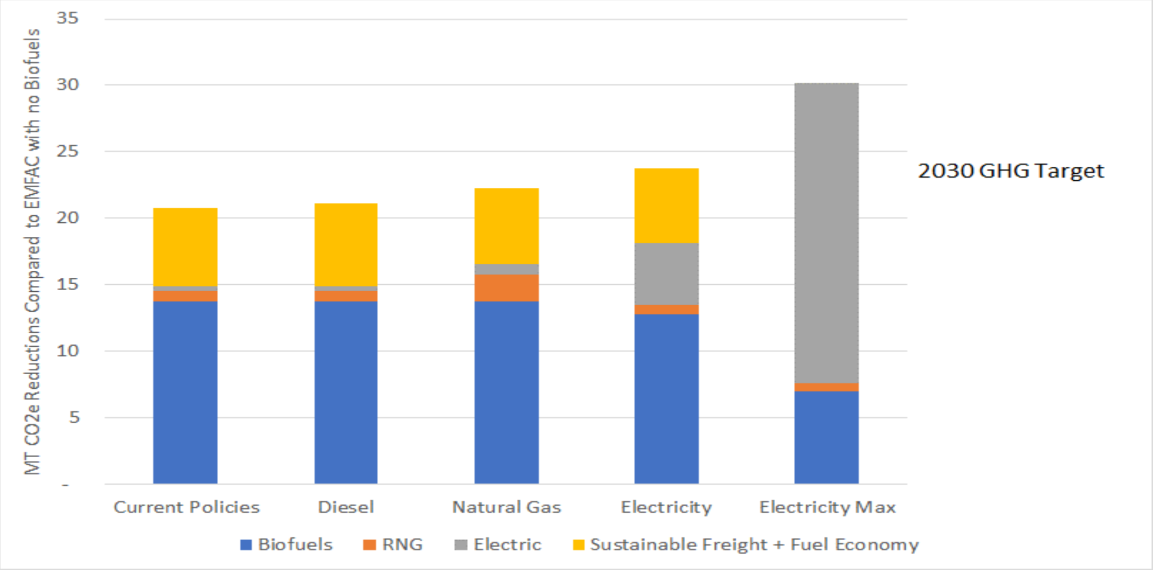
Figure III-6. Scenario GHG Emissions Comparison



The Current Policies scenario, which includes biofuels driven by LCFS compliance and a 25 percent freight efficiency improvement from the Sustainable Freight Action Plan, can almost achieve 2030 GHG policy goals. The diesel scenario achieves marginal additional reductions in GHG emissions mainly beyond 2030 as a result of continued efficiency improvements. The Natural Gas scenario achieves greater reductions than the Diesel scenario but is ultimately limited by the overall availability of RNG and is therefore also insufficient to meet the 2030 or 2050 GHG policy goals. After 2039 an increasing portion of natural gas vehicles is fueled with fossil natural gas as the cap of 750 million DGE of RNG is reached.

To determine the magnitude of the impact from the strategies included in the different scenarios to overall emission reductions, ICF ran the EMFAC model with no adjustments and no biofuels. Figure III-7 shows the contribution of the emission reductions from the various fuels and strategies.

Figure III-7. Strategy Contribution to 2030 Emission Reductions in MMT CO_2e

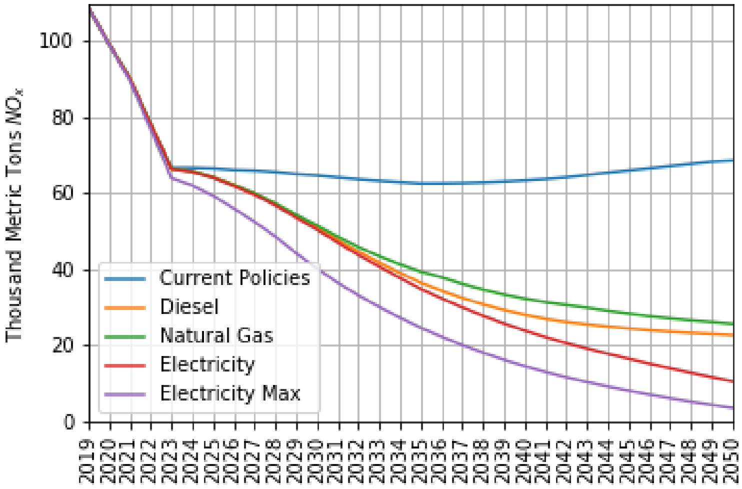


ICF attributed emissions reductions to strategies and fuels by assuming liquid biofuels displace conventional diesel on a one-to-one basis, and RNG and electricity displace diesel considering their respective energy economy ratios (EERs). ICF then attributed the remaining reductions to a combination of sustainable freight and further increases in vehicle efficiency. Outside of the Electricity Max scenario, liquid biofuels are the largest contributor to GHG reductions, with sustainable freight and fuel efficiency improvements the second largest.

1.3 NOx Emissions

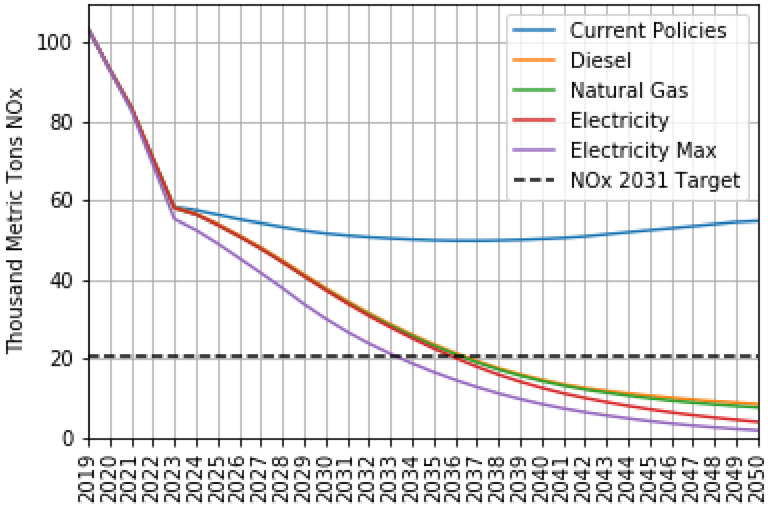
Figure III-8 and Figure III-9 show the lifecycle and tailpipe NOx emission results.

Figure III-8. Scenario Lifecycle NOx Emission Comparison



From a lifecycle emission perspective, upstream and out-of-state emissions in the Natural Gas scenario result in lower overall NOx emission reductions compared to the Electricity scenarios or implementation of low-NOx diesel in the Diesel scenario .The Electricity scenarios are the only scenarios with lower emissions than the diesel scenario.

Figure III-9. Scenario Tailpipe NOx Emission Comparison

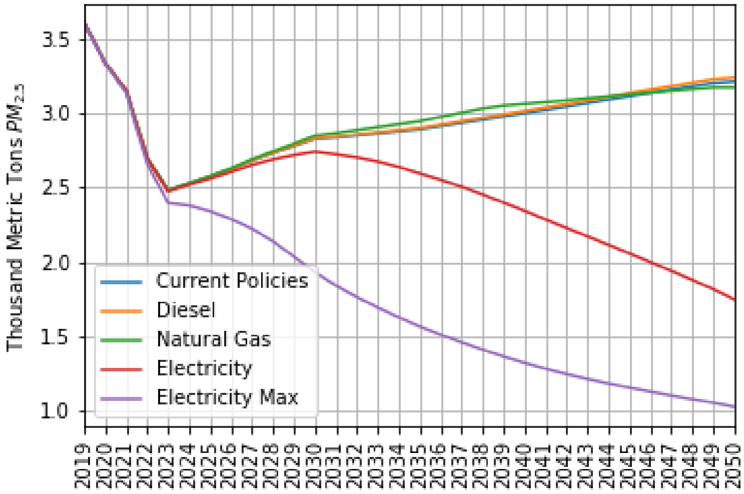


From a strictly tailpipe perspective, the BEV Max is the only scenario that comes close to the 2031 NOx target, achieving it in 2033 as shown in Figure III-9.   Accelerated turnover of model year 2024 or older trucks by 2031, or actions taken in other sectors of the economy, could be pursued to achieve the targets, but were outside the scope of this analysis.

1.4 PM2.5 Emissions

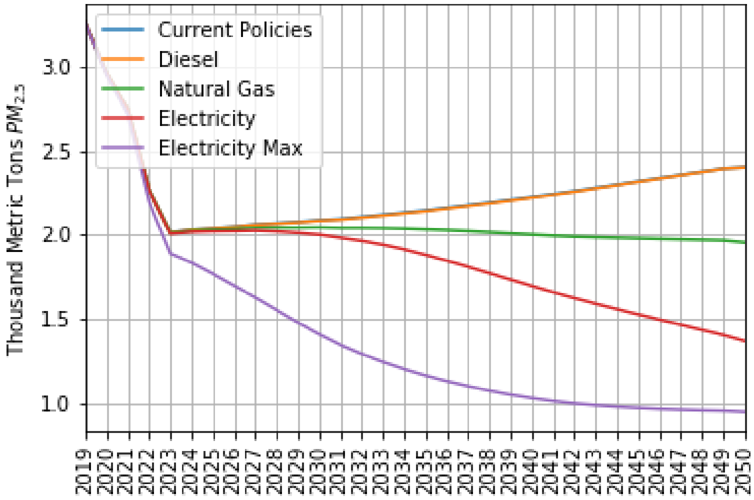
Figure III-10 and Figure III-11show PM2.5 full lifecycle and tailpipe emissions results for the scenarios.

Figure III-10. Scenario PM2.5 Emission Comparison



From a lifecycle perspective, only the Electricity and Electricity Max scenarios achieve emission reductions compared to the Current Policies scenario.

Figure III-11. Scenario Tailpipe PM2.5 Emission Comparison



All scenarios, except Electricity Max, have similar 2030 total tailpipe emissions. The Natural Gas scenario does achieve reductions compared to the Current Policies scenario in 2050, but the Electricity and Electricity Max scenarios achieve much more significant reductions.

IV. Conclusions

The main conclusion from the Scenario Analysis is that increased electrification is required to meet both 2030 and 2050 GHG goals and can significantly help in meeting 2031 NOx requirements. The Electricity scenario, which achieves 100,000 electric MD and HD electric vehicles in 2030 and over 1.4 million in 2050, is the only scenario (outside of the BEV Max upper limit scenario) able to achieve both the 2030 and 2050 GHG goals. If the reductions from other measures built into the scenarios--increased diesel fuel efficiency, use of biodiesel and renewable diesel for compliance with the low carbon fuel standard (LCFS), and 25 percent fuel consumption reductions from sustainable freight-- are not achieved, electric trucks will have to play an even more important role in achieving GHG reduction goals. The electrification scenarios are the only scenarios that achieve significant PM reductions in the 2050 timeframe. The RNG limit of 750 million DGE in the transportation sector puts a cap on the GHG reduction potential from natural gas vehicles.

The Diesel, Natural Gas, Electricity, and Electricity Max scenarios are all able to show significant NOx emission reductions compared to the Current Policies scenario. Deployment of low-NOx diesel engines causes most of the reductions in the near term and limits or eliminates the incremental tailpipe reductions of BEVs or natural gas vehicles. For MD and HD vehicles to achieve their proportional NOx reductions to achieve 2031 requirements for SCAQMD and the San Joaquin Valley Air Pollution Control District, regulation or policy to retire pre-2024 engines are likely necessary, or additional NOx reductions from other sectors will be needed.

The scenario results do not quantify elements related to sustainability, including concerns about soil erosion, pesticide use, water pollution, food for fuel issues, or other concerns from the use of liquid biofuels. The Balanced Scorecard addresses concerns related to potential use of liquid biofuels in a qualitative manner. For RNG, as stated earlier, this assessment relied on the potential available volumes from waste feedstocks, which would not include similar concerns related to the use of liquid biofuels.

V. Appendix A – Additional Results

Appendix A contains additional scenarios and detailed graphs of both the additional scenarios and the five scenarios included report the results.

Table V-1: Scenario Summary (additional scenarios)

	Current Policies	Diesel	Natural Gas	Electricity	Electricity Max
Phase 2 GHG Standards	✓	✓	✓	✓	✓
Senate Bill 1 (Truck and Bus Regulation)	✓	✓	✓	✓	✓
Innovative Clean Transit	✓	✓	✓+	✓+	✓+
Sustainable Freight Action Plan	✓	✓	✓	✓	✓
San Pedro Bay Ports Clean Air Action Plan	✓	✓	✓	✓	✓
Implementing Low NOx Diesel Engines		✓	✓	✓	✓
Further Tightening of Phase 2 GHG Standards Beyond 2027		✓	✓+	✓+	✓+
Error! Reference source not found.			✓NG+	✓EV+	✓EV+
Zero-Emission Airport Shuttle Regulation			✓+	✓+	✓+
Out-of-State Truck Requirement			✓NG	✓EV	✓EV+

✓ Strategy included in scenario
+ Adjustments were made to make the strategy more aggressive.
EV: Vehicle sales were assumed to be electric.
NG: Vehicle sales were assumed to be natural gas.
Mix: Vehicle sales were a mix of electric and NGVs.

1. Current Policies Scenario

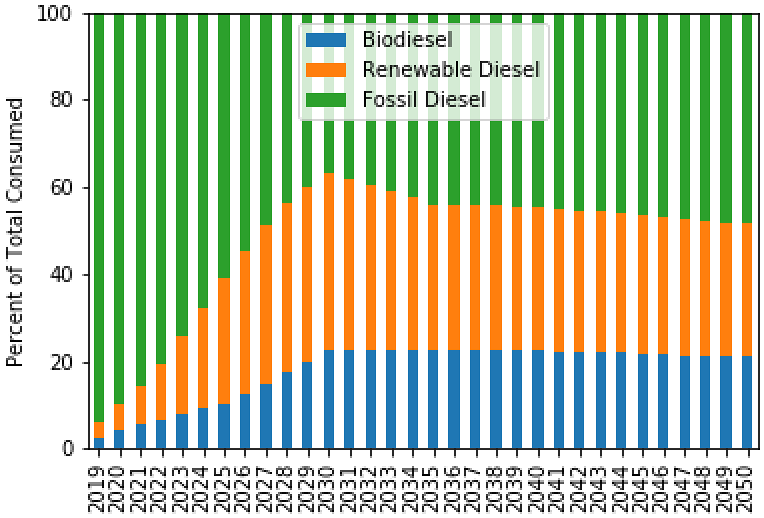
1.1 Current Policies Scenario Description

This scenario adds current policies to the EMFAC assumptions.

Table V-2: Strategies Included in Current Policies Scenario

Phase 2 GHG Standards	None
Senate Bill 1 (Truck and Bus Regulation)	None
Innovative Clean Transit	None
Sustainable Freight Action Plan	None
San Pedro Bay Ports Clean Air Action Plan	None

Exhibit 1: Current Policies Diesel Blend



1.2 Vehicle Profile

Exhibit 2: Current Policies Vehicle Sales by Fuel Type

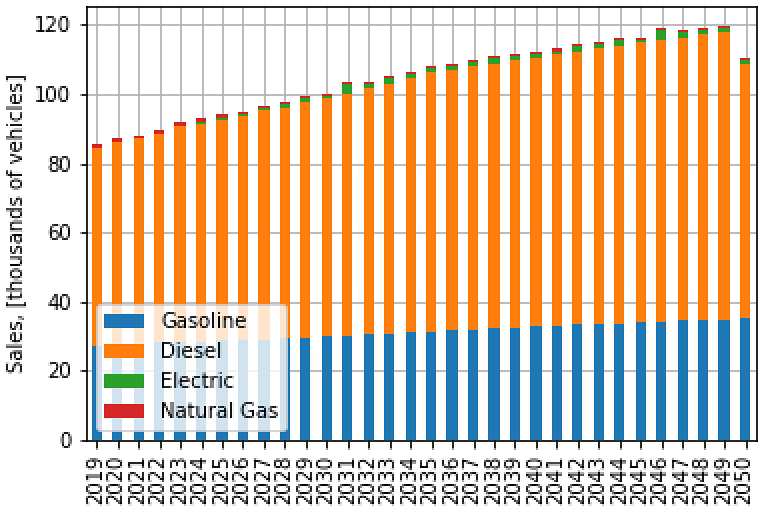
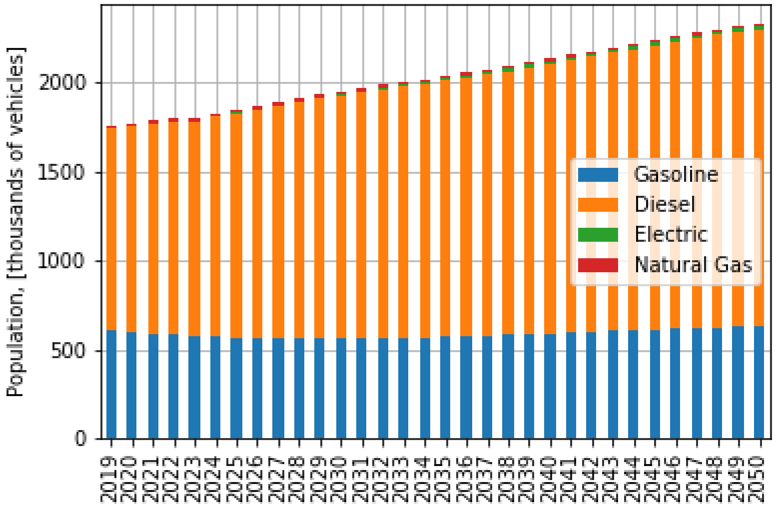
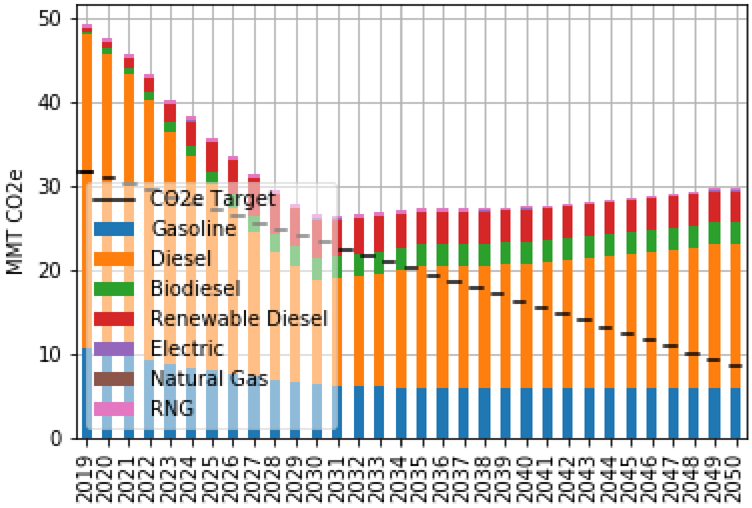


Exhibit 3: Current Policies Vehicle Population by Fuel Type



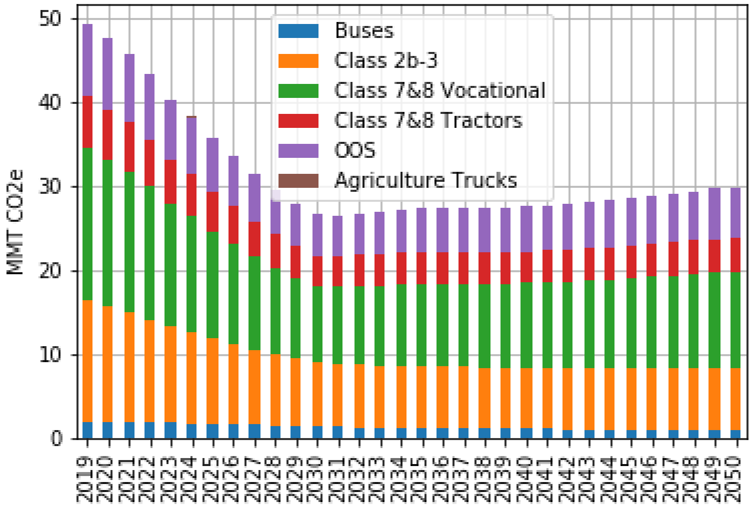
1.3 CO₂e Emissions

Exhibit 4: Current Policies GHG Emissions by Fuel Type



1.4 CO₂e Emissions by Category

Exhibit 5: Current Policies GHG Emissions by Vehicle Category



1.5 NOx Emissions

Exhibit 6: Current Policies Tailpipe NOx Emissions by Fuel Type

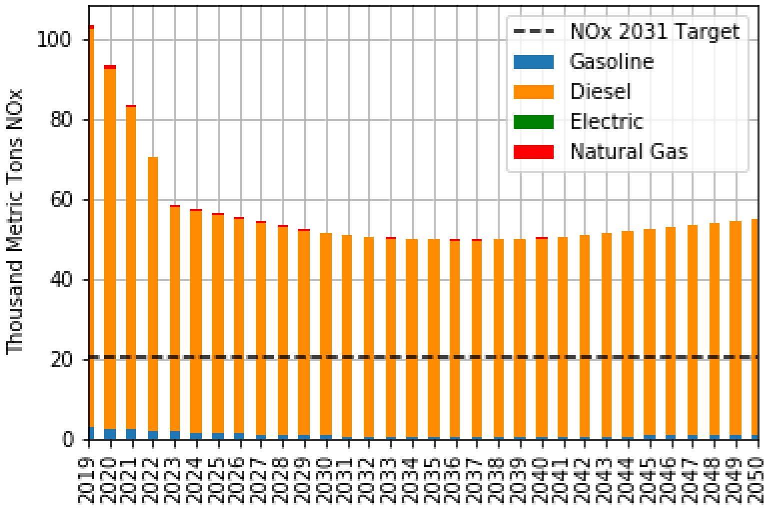
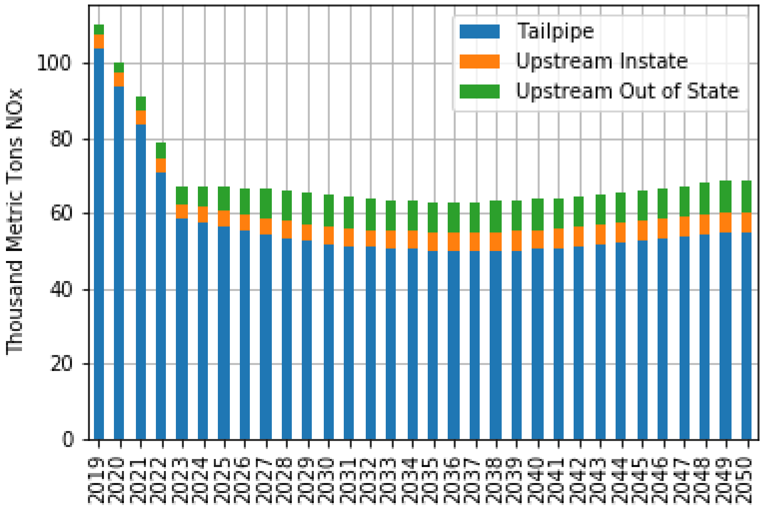


Exhibit 7: Current Policies Tailpipe vs. Upstream NOx Emissions



1.6 NOx Emissions by Category

Exhibit 8: Current Policies Tailpipe NOx Emissions by Vehicle Category

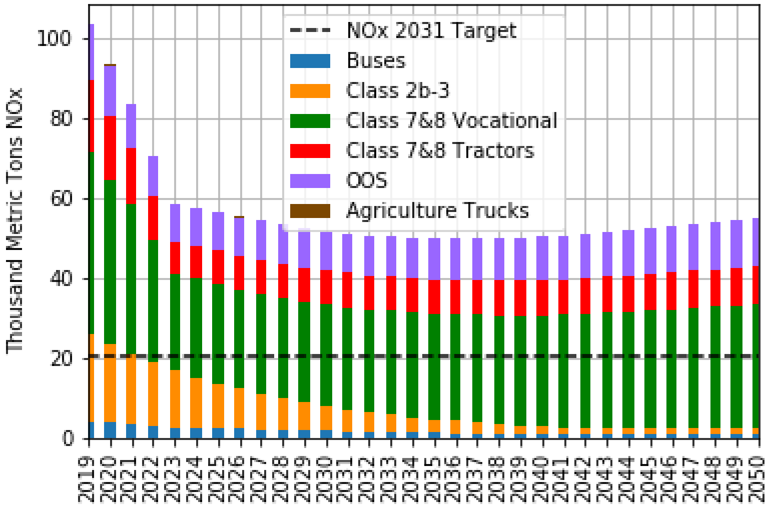
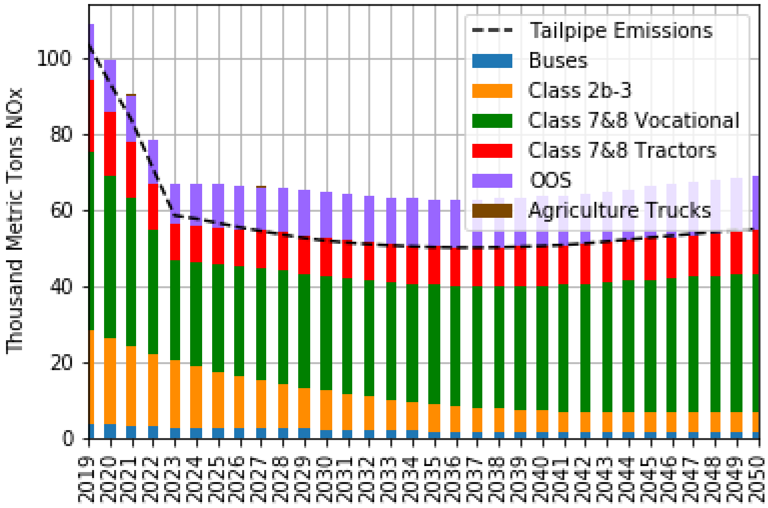


Exhibit 9: Current Policies Lifecycle NOx Emissions by Vehicle Category



1.7 PM2.5 Emissions

Exhibit 10: Current Policies Tailpipe PM2.5 Emissions

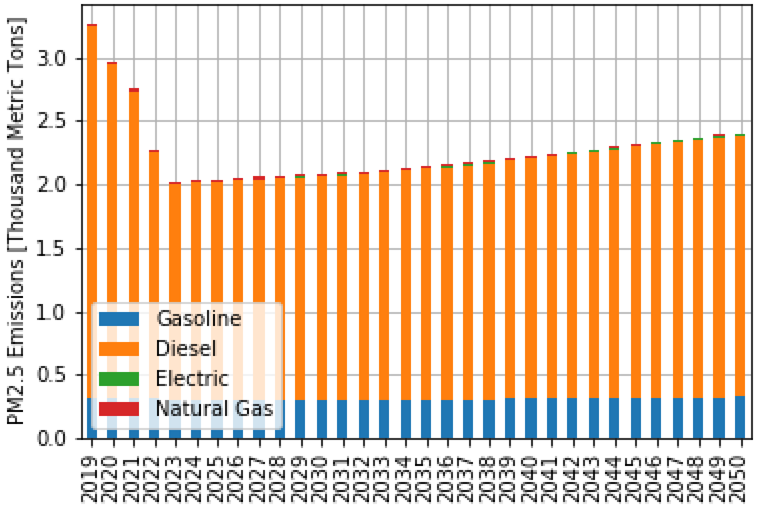
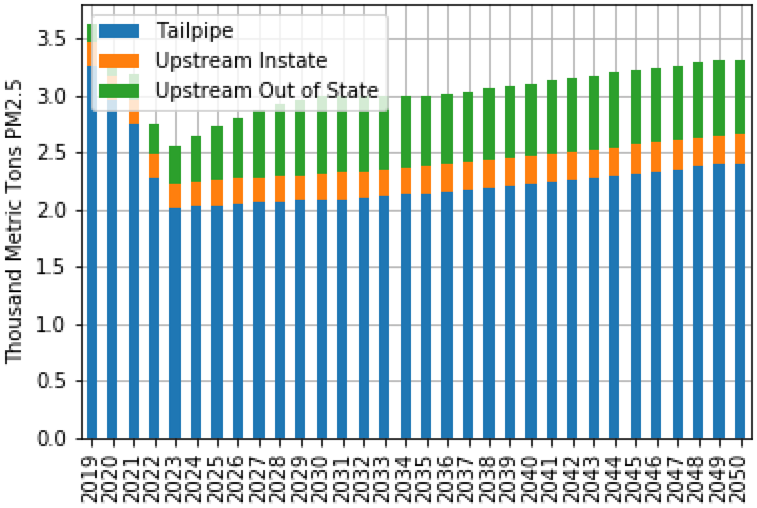


Exhibit 11: Current Policies Tailpipe vs. Upstream PM2.5 Emissions



1.8 PM2.5 Emissions by Category

Exhibit 12: Current Policies Tailpipe PM2.5 Emission by Vehicle Category

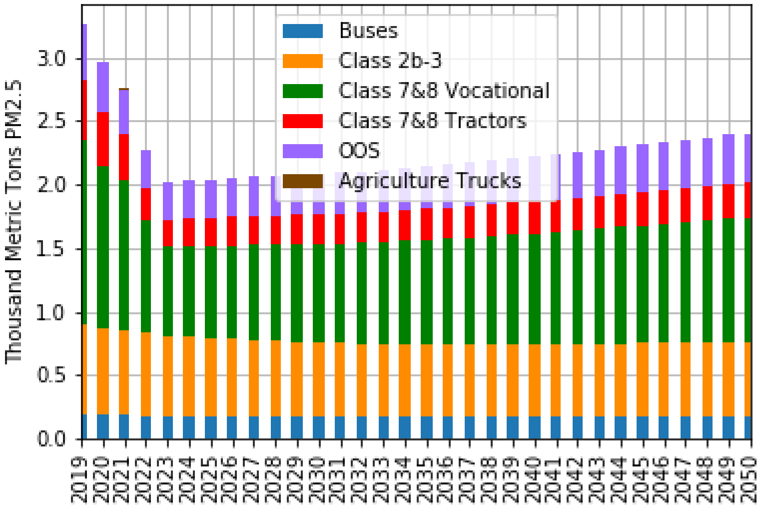
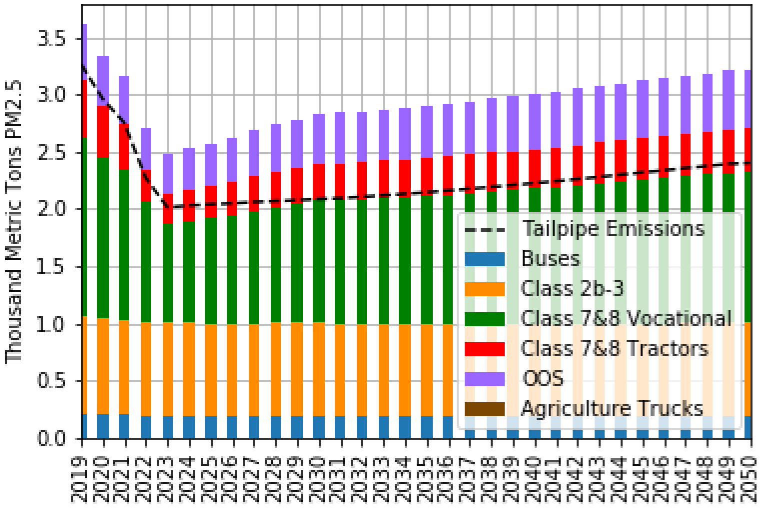
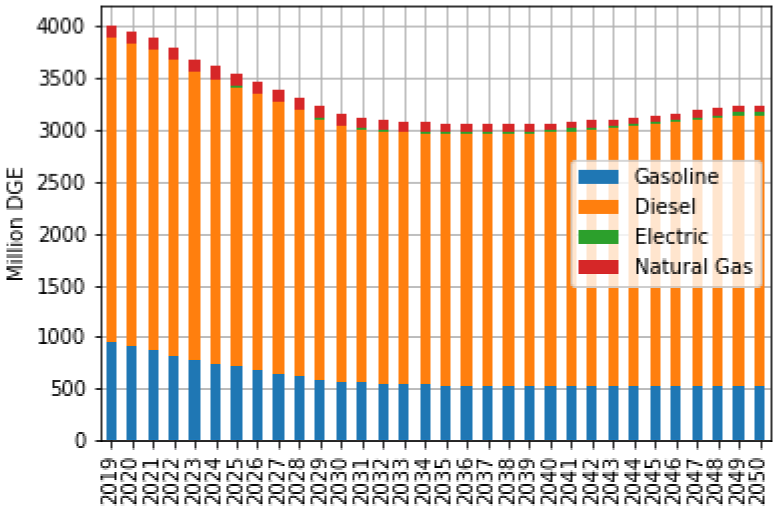


Exhibit 13: Current Policies Lifecycle PM2.5 Emissions by Category



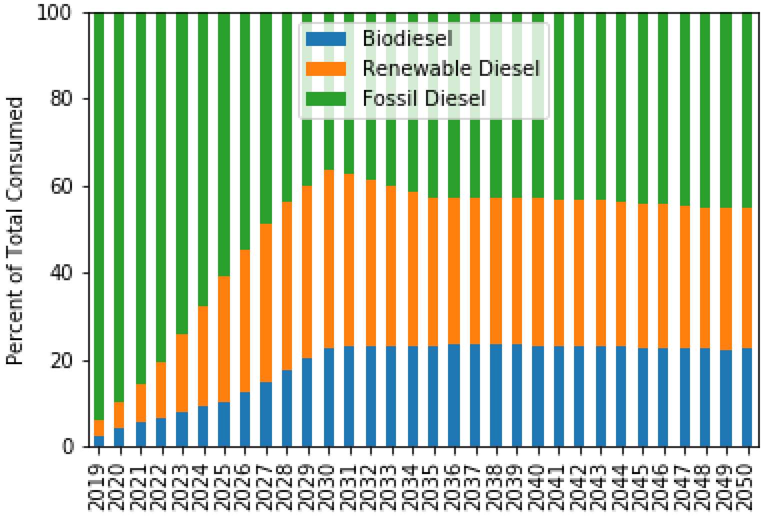
1.9 Fuel Consumption

Exhibit 14: Current Policies Fuel Consumption



2. Diesel Scenario

Exhibit 15: Diesel Scenario Diesel Blend



2.1 Vehicle Profile

Exhibit 16: Diesel Scenario Vehicle Sales by Fuel Type

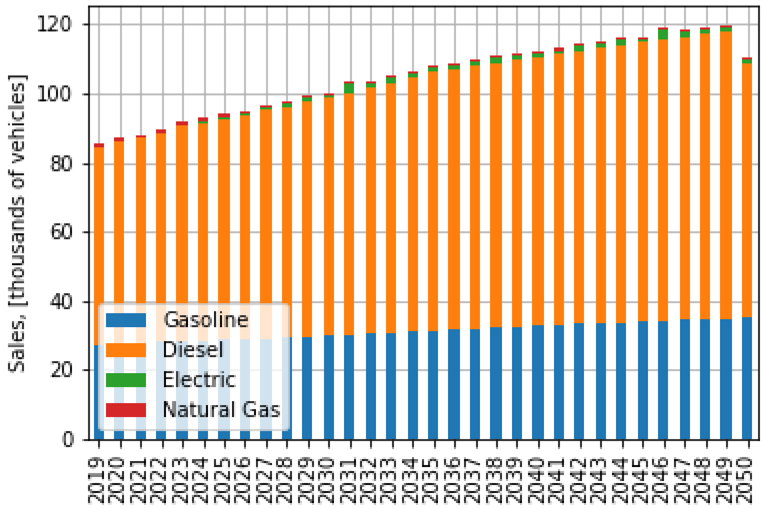
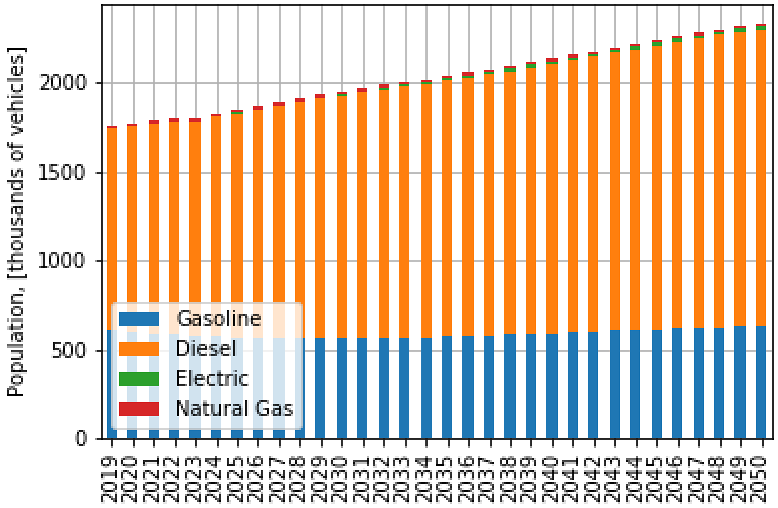
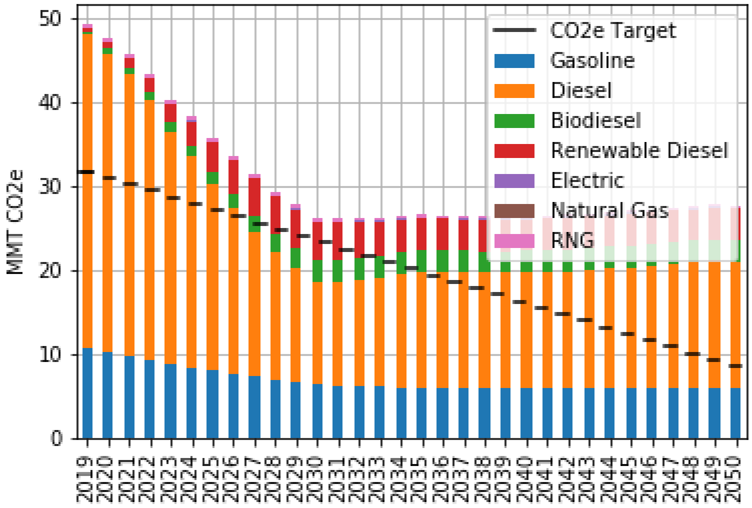


Exhibit 17: Diesel Scenario Vehicle Population by Fuel Type



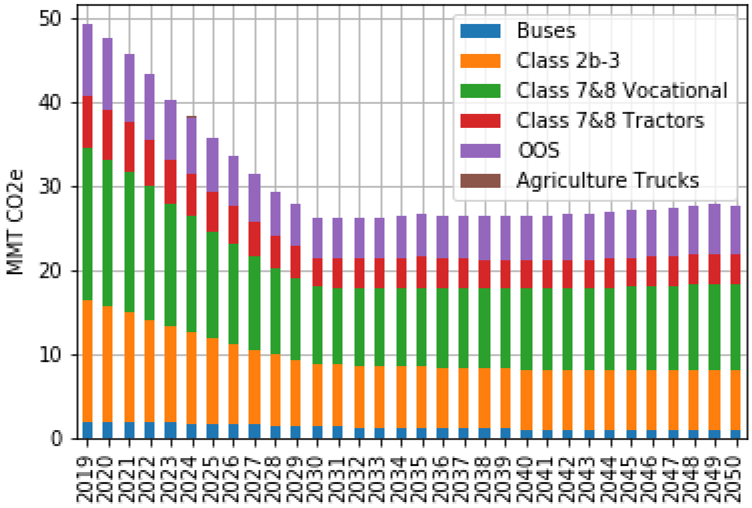
2.2 CO2e Emissions

Exhibit 18: Diesel Scenario GHG Emissions by Fuel Type



2.3 CO$_2$e Emissions by Category

Exhibit 19: Diesel Scenario GHG Emissions by Vehicle Category



2.4 NOx Emissions

Exhibit 20: Diesel Scenario Tailpipe NOx Emissions by Fuel Type

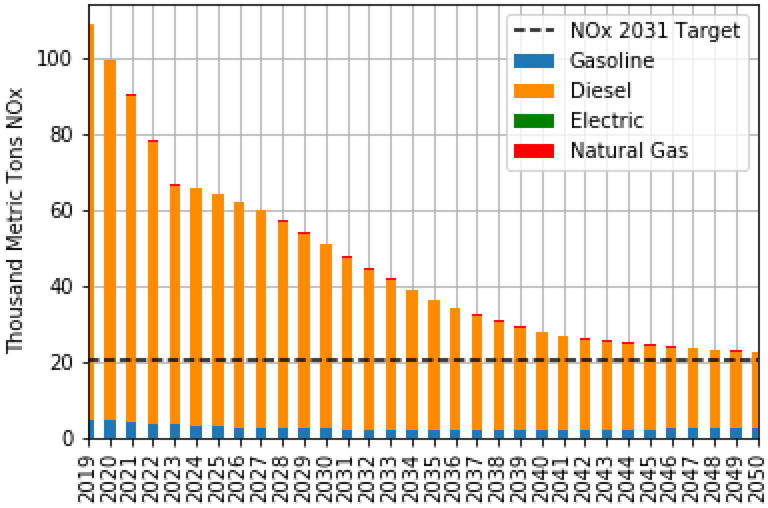
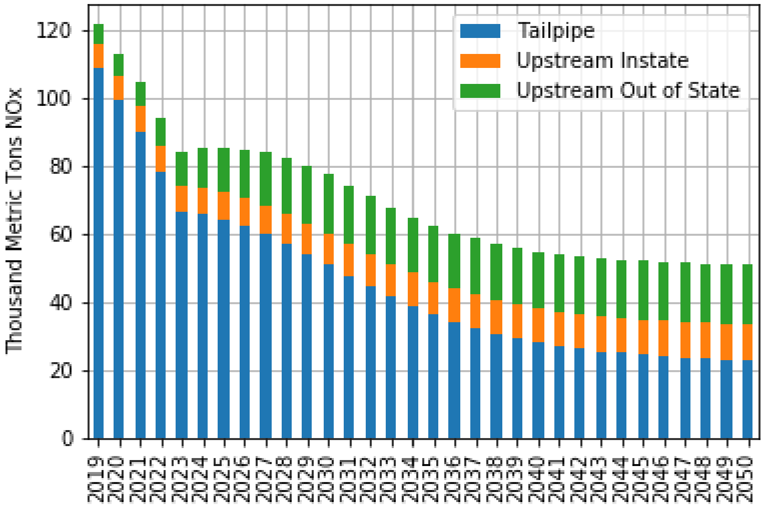


Exhibit 21: Diesel Scenario Tailpipe vs. Upstream NOx Emissions



2.5 NOx Emissions by Category

Exhibit 22: Diesel Scenario Tailpipe NOx Emissions by Vehicle Category

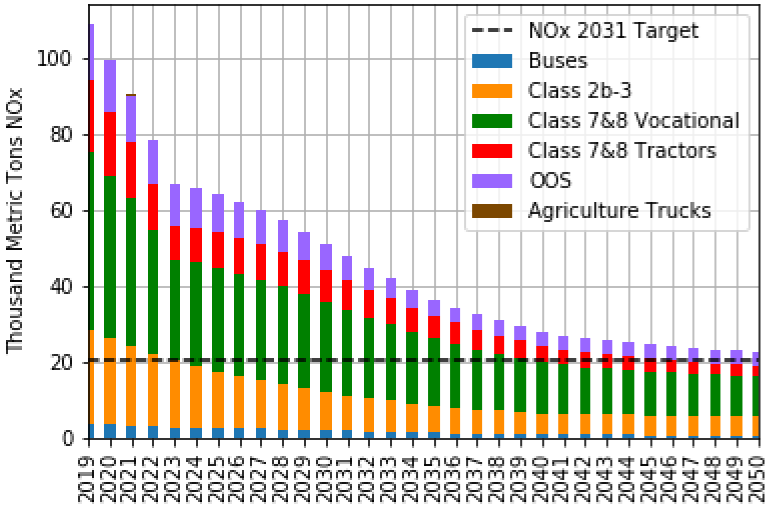
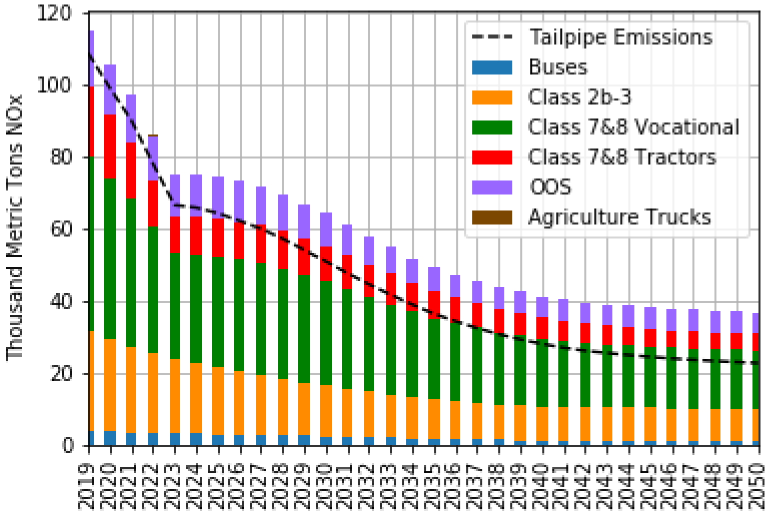


Exhibit 23: Diesel Scenario Lifecycle NOx Emissions by Vehicle Category



2.6 PM2.5 Emissions

Exhibit 24: Diesel Scenario Tailpipe PM2.5 Emissions

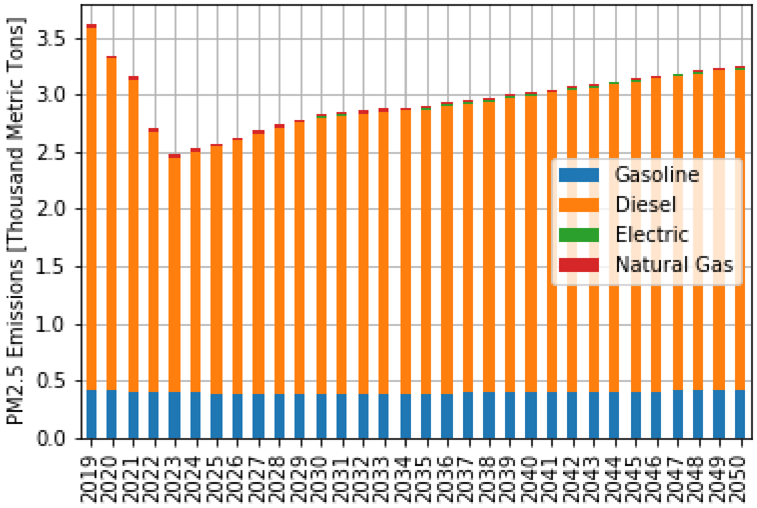
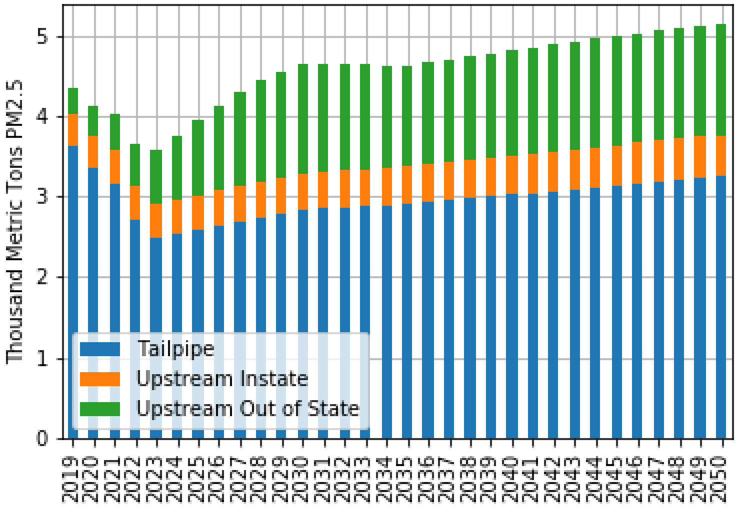


Exhibit 25: Diesel Scenario Tailpipe vs Upstream PM2.5 Emissions



2.7 PM2.5 Emissions by Category

Exhibit 26: Diesel Scenario Tailpipe PM2.5 Emissions by Vehicle Category

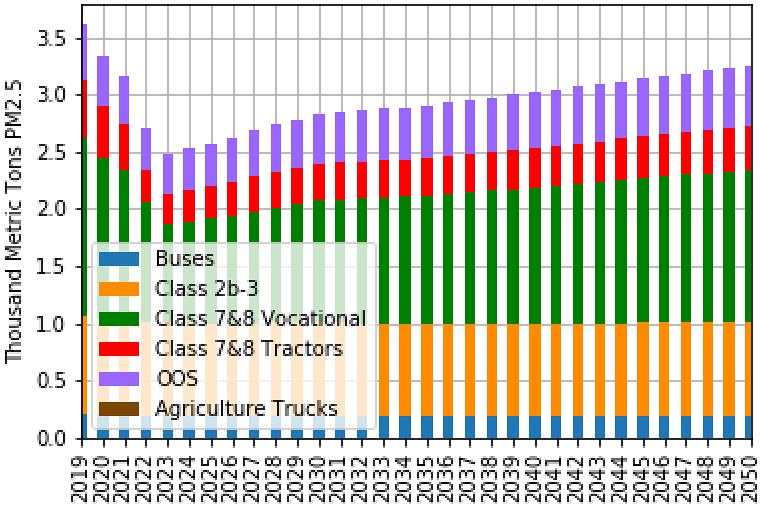
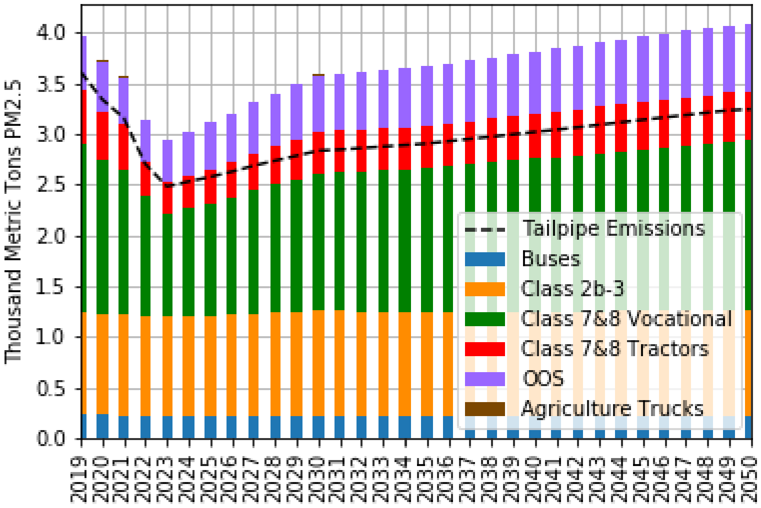
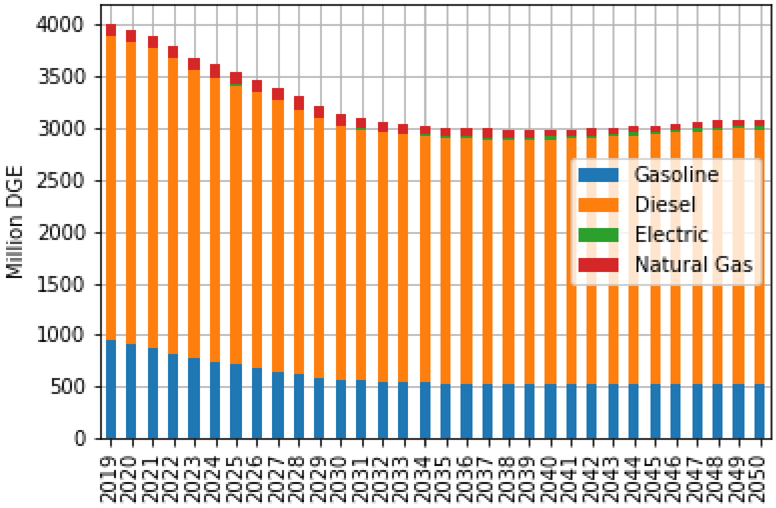


Exhibit 27: Diesel Scenario Lifecycle PM2.5 Emissions by Vehicle Category



2.8 Fuel Consumption

Exhibit 28: Diesel Scenario Fuel Consumption



3. Natural Gas Scenario

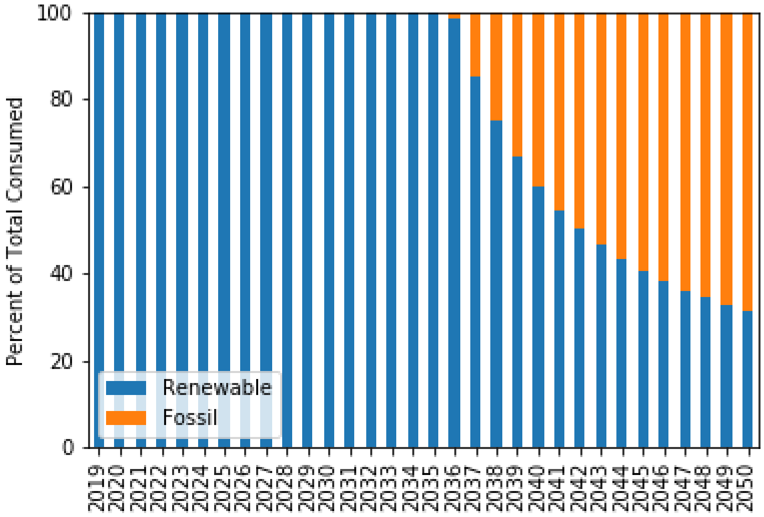
3.1 Natural Gas Scenario Description

The purpose of Natural Gas scenario is to attempt to meet 2030 and 2050 targets with an emphasis on natural gas. After several iterations, this scenario became a mirror to the Electricity scenario, using NGVs to comply for the Advanced Technology Deployment strategy instead of BEVs. This scenario also assumes that a percentage of out-of-state trucks that operate in California would be natural gas.

Table V-3: Strategies Included in Natural Gas Scenario

<table>
<tr><th>Strategies Included</th><th>Adjustments Made</th></tr>
<tr><td>Phase 2 GHG Standards</td><td>None</td></tr>
<tr><td>Senate Bill 1 (Truck and Bus Regulation)</td><td>None</td></tr>
<tr><td>Innovative Clean Transit</td><td>• Includes all bus EMFAC categories, rather than just urban buses. Now includes: urban bus, school bus, motor coach, other bus, all other buses.</td></tr>
<tr><td>Sustainable Freight Action Plan</td><td>None</td></tr>
<tr><td>San Pedro Bay Ports Clean Air Action Plan</td><td>None</td></tr>
<tr><td>Implementing Low NOx Diesel Engines</td><td>None</td></tr>
<tr><td>Further Tightening of Phase 2 GHG Standards Beyond 2027</td><td>• Increased fuel economy improvement to 20% by 2050
• Includes in-state and out-of-state trucks</td></tr>
<tr><td>Advanced Technology Deployment</td><td>• Assumed all new sales are NGVs
• Increased the assumed rate of NGV sales from 2030-2050
<table>
<tr><th>Model Year</th><th>Class 2B-3</th><th>Class 4-8 Vocational</th><th>Class 7-8 Tractors</th></tr>
<tr><td>2030</td><td>15%</td><td>50%</td><td>15%</td></tr>
<tr><td>2050</td><td>100%</td><td>100%</td><td>100%</td></tr>
</table></td></tr>
<tr><td>Zero-Emission Airport Shuttle Regulation</td><td>• 100% of fleet electric by 2025, rather than 2035</td></tr>
<tr><td>Out-of-State Truck Requirement</td><td>• Assumed NGVs</td></tr>
</table>

Exhibit 29: Natural Gas Scenario Natural Gas Blend



3.2 Vehicle Profile

Exhibit 30: Natural Gas Scenario Vehicle Sales by Fuel Type

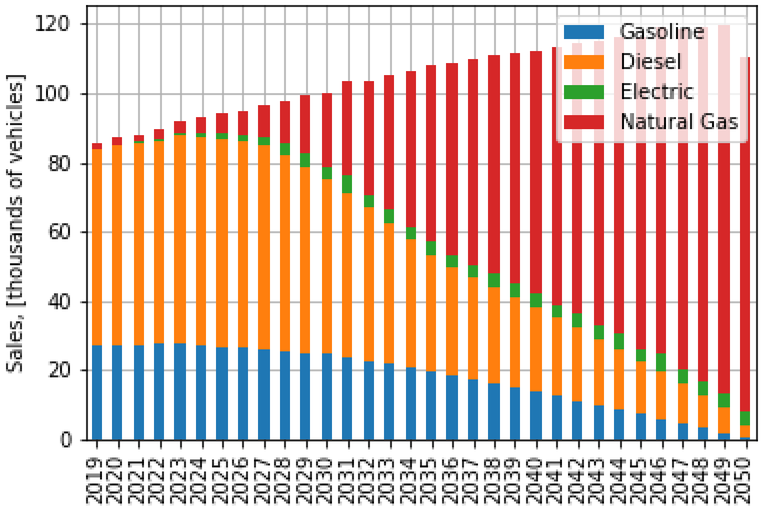
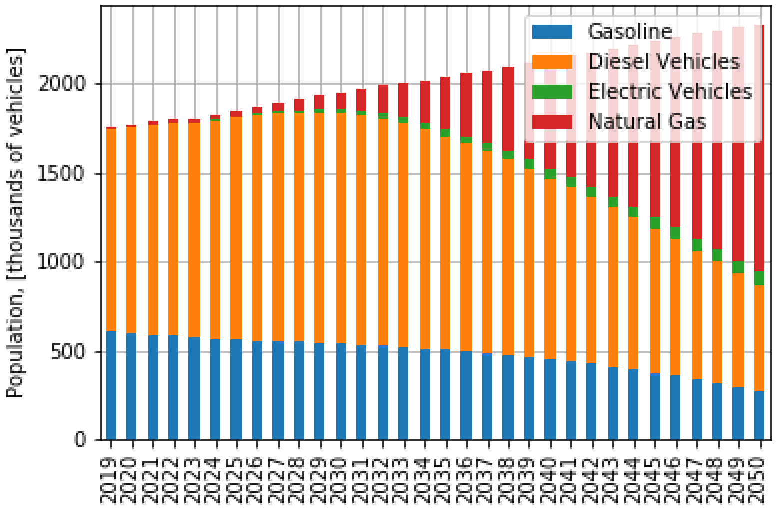
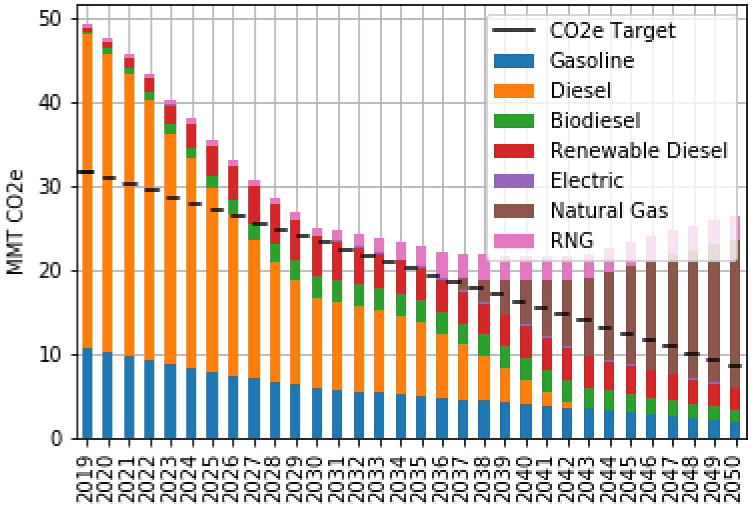


Exhibit 31: Natural Gas Scenario Vehicle Population by Fuel Type



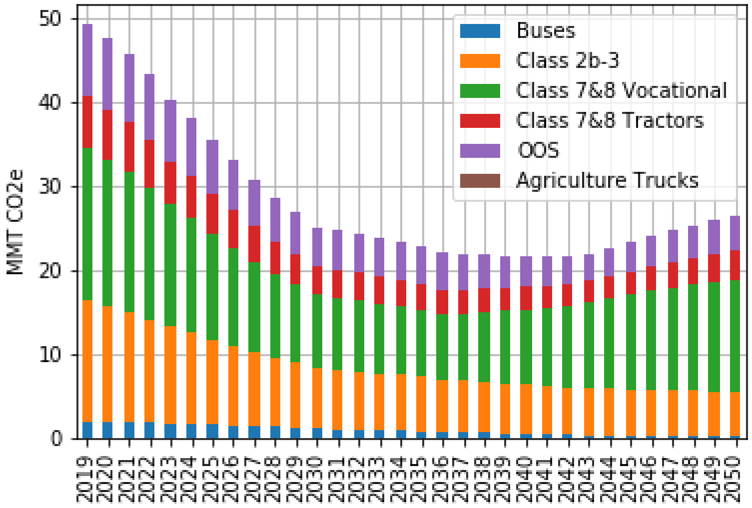
3.3 CO₂e Emissions

Exhibit 32: Natural Gas Scenario GHG Emissions by Fuel Type



3.4 CO₂e Emissions by Category

Exhibit 33: Natural Gas Scenario GHG Emissions by Vehicle Category



3.5 NOx Emissions

Exhibit 34: Natural Gas Scenario Tailpipe NOx Emissions by Fuel Type

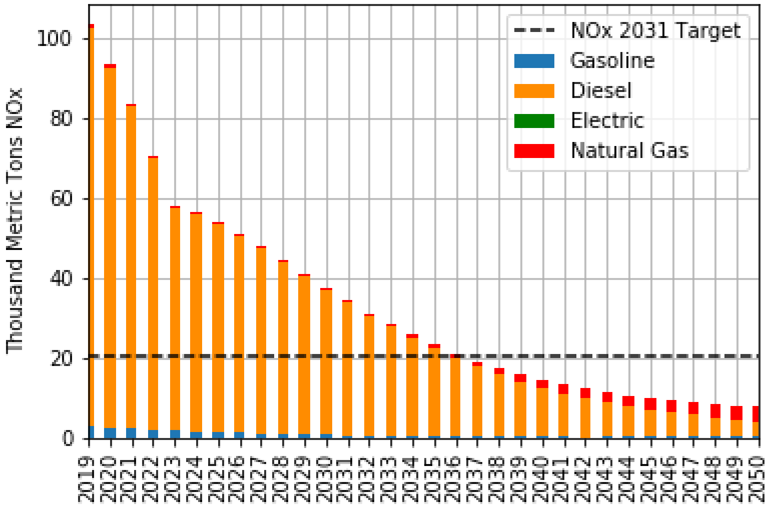
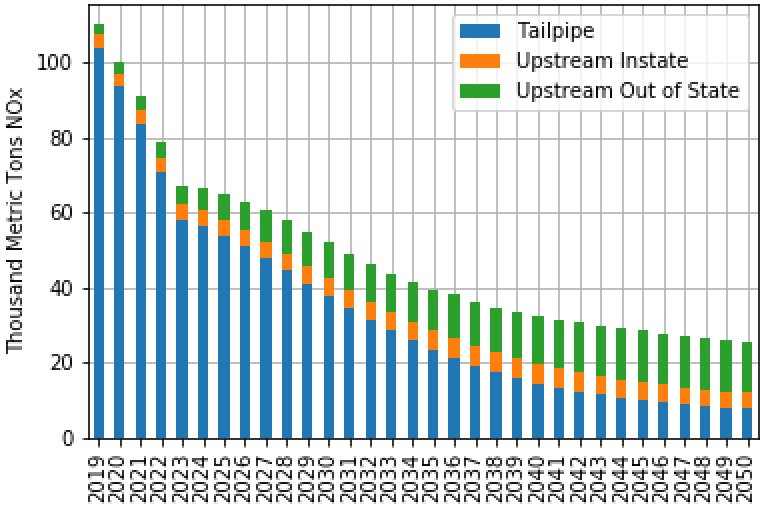


Exhibit 35: Natural Gas Scenario Tailpipe vs. Upstream NOx Emissions



3.6 NOx Emissions by Category

Exhibit 36: Natural Gas Scenario Tailpipe NOx Emissions by Vehicle Category

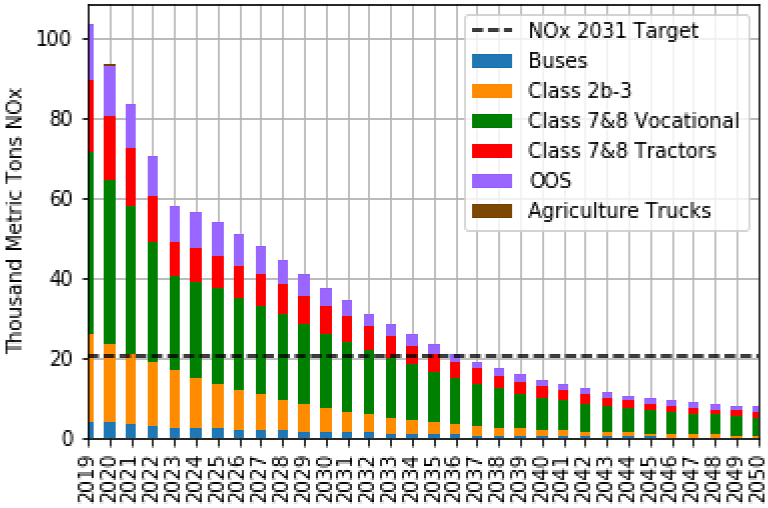
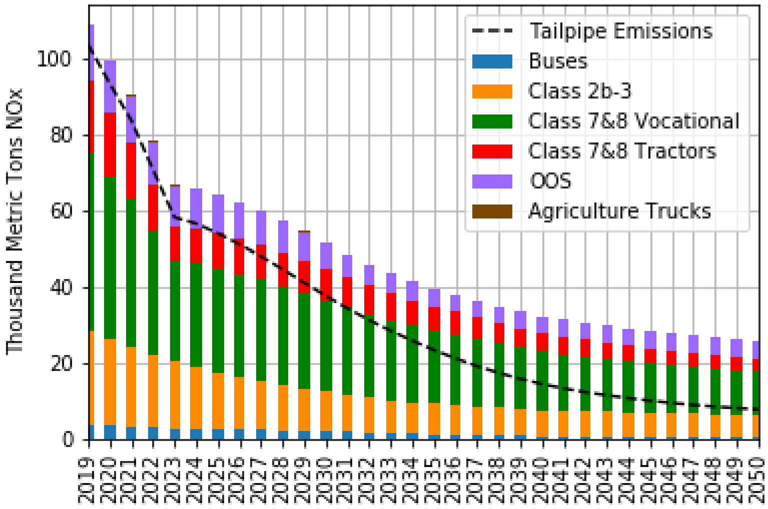


Exhibit 37: Natural Gas Scenario Lifecycle NOx Emissions by Vehicle Category



3.7 PM2.5 Emissions

Exhibit 38: Natural Gas Scenario Tailpipe PM2.5 Emissions

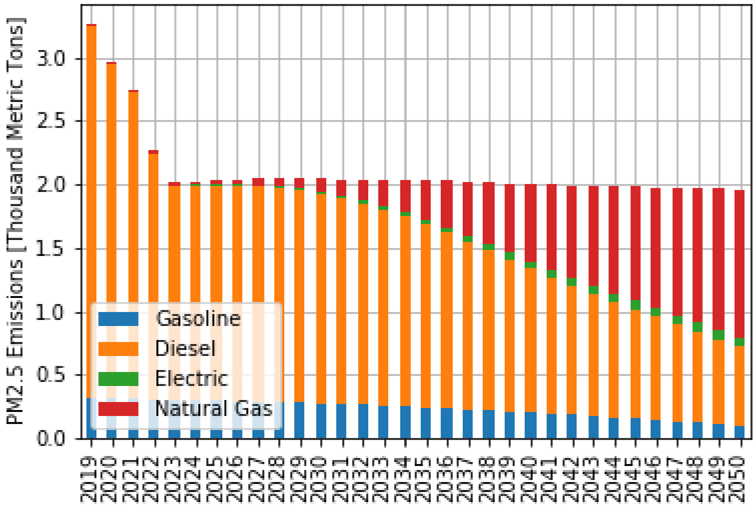
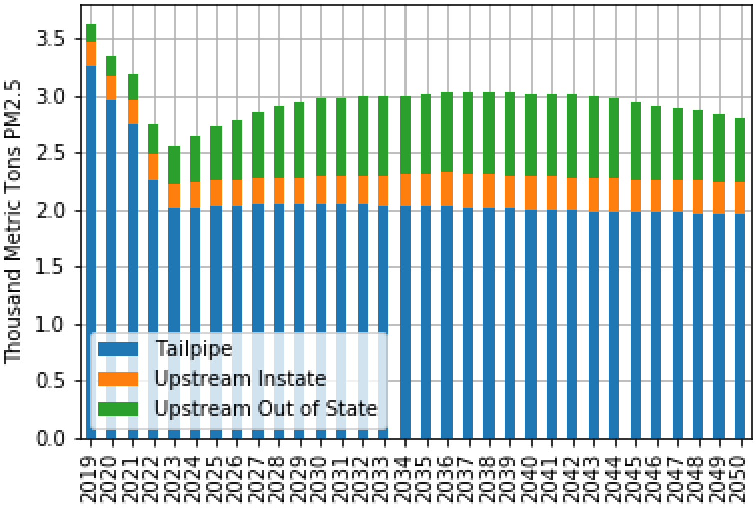


Exhibit 39: Natural Gas Scenario Tailpipe vs. Upstream PM2.5 Emissions



3.8 PM2.5 Emissions by Category

Exhibit 40: Natural Gas Scenario Tailpipe PM2.5 Emissions by Vehicle Category

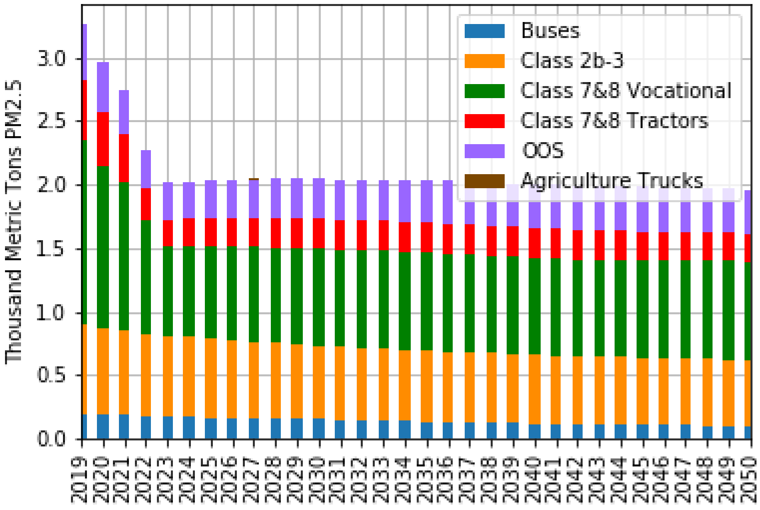
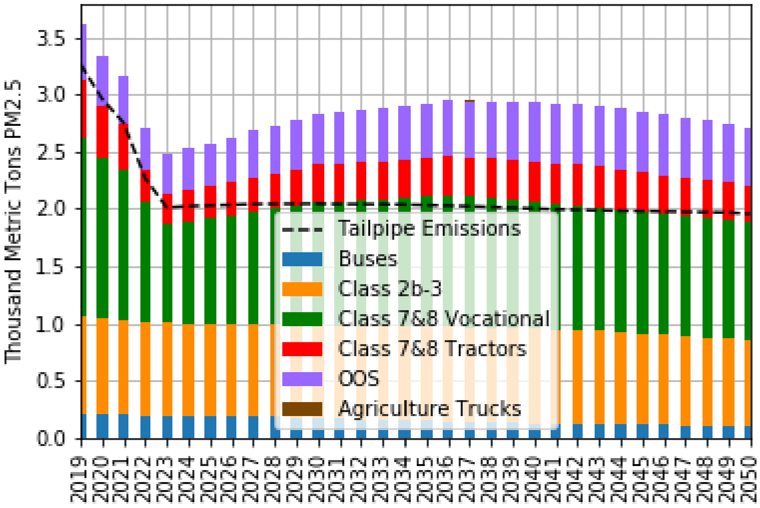
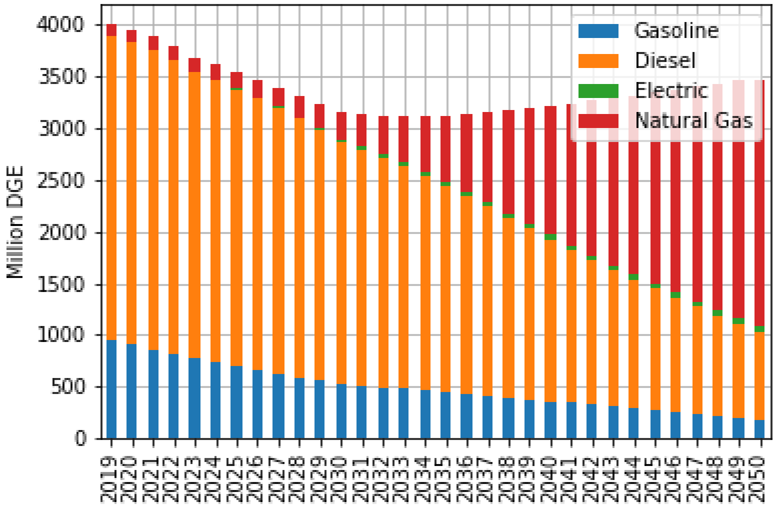


Exhibit 41: Lifecycle PM2.5 Emissions by Vehicle Category



3.9 Fuel Consumption

Exhibit 42: Natural Gas Scenario Fuel Consumption



4. Electricity Scenario

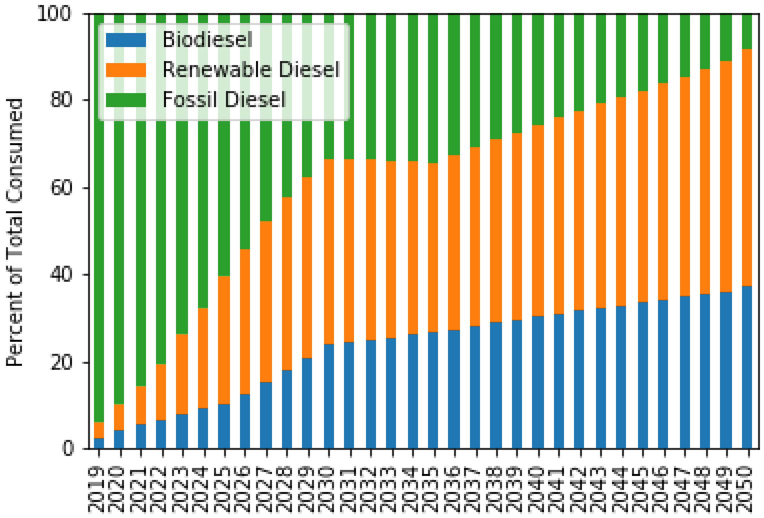
4.1 Electricity Scenario Description

The purpose of the Electricity scenario is to attempt to meet 2030 and 2050 targets with an emphasis on electric trucks and buses. This scenario implemented electric vehicles for the Advanced Technology Deployment strategy.

Table V-4: Strategies Included in Electricity Scenario

<table>
<tr><th>Strategies Included</th><th>Adjustments Made</th></tr>
<tr><td>Phase 2 GHG Standards</td><td>None</td></tr>
<tr><td>Senate Bill 1 (Truck and Bus Regulation)</td><td>None</td></tr>
<tr><td>Innovative Clean Transit</td><td>• Includes all bus EMFAC categories, rather than just urban buses. Now includes: urban bus, school bus, motor coach, other bus, all other buses.</td></tr>
<tr><td>Sustainable Freight Action Plan</td><td>None</td></tr>
<tr><td>San Pedro Bay Ports Clean Air Action Plan</td><td>None</td></tr>
<tr><td>Implementing Low NOx Diesel Engines</td><td>None</td></tr>
<tr><td>Further Tightening of Phase 2 GHG Standards Beyond 2027</td><td>• Increased fuel economy improvement to 20% by 2050
• Includes in-state and out-of-state trucks</td></tr>
<tr><td>Advanced Technology Deployment</td><td>• Assumed all new sales are BEVs
• Increased the assumed rate of BEV sales from 2030-2050
<table>
<tr><th>Model Year</th><th>Class 2B-3</th><th>Class 4-8 Vocational</th><th>Class 7-8 Tractors</th></tr>
<tr><td>2030</td><td>15%</td><td>50%</td><td>15%</td></tr>
<tr><td>2050</td><td>100%</td><td>100%</td><td>100%</td></tr>
</table></td></tr>
<tr><td>Zero-Emission Airport Shuttle Regulation</td><td>• 100% of fleet electric by 2025, rather than 2035</td></tr>
<tr><td>Out-of-State Truck Requirement</td><td>• Assumed BEVs</td></tr>
</table>

Exhibit 43: Electricity Scenario Diesel Blend



4.2 Vehicle Profile

Exhibit 44: Electricity Scenario Vehicles by Fuel Type

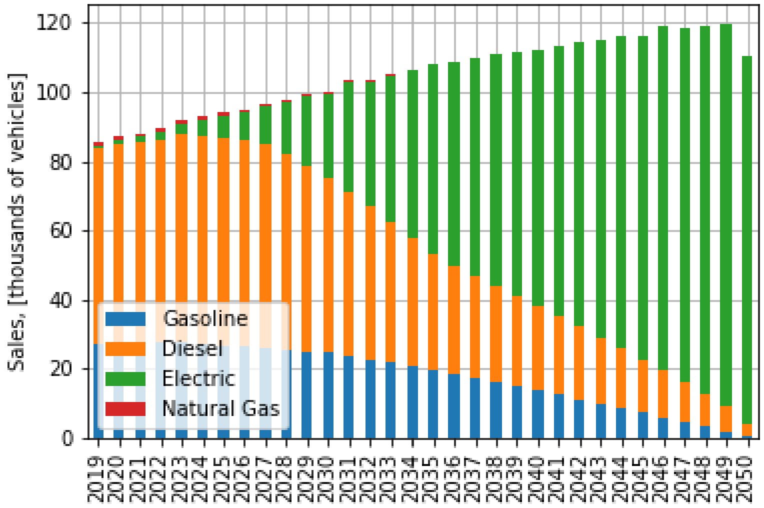
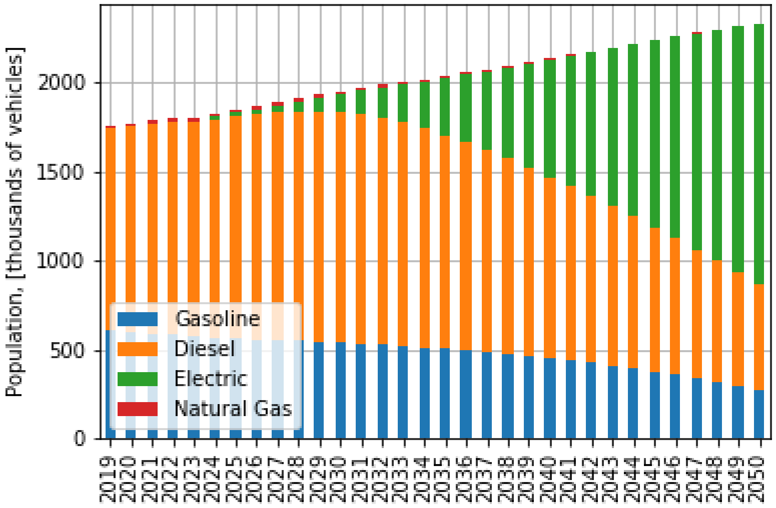
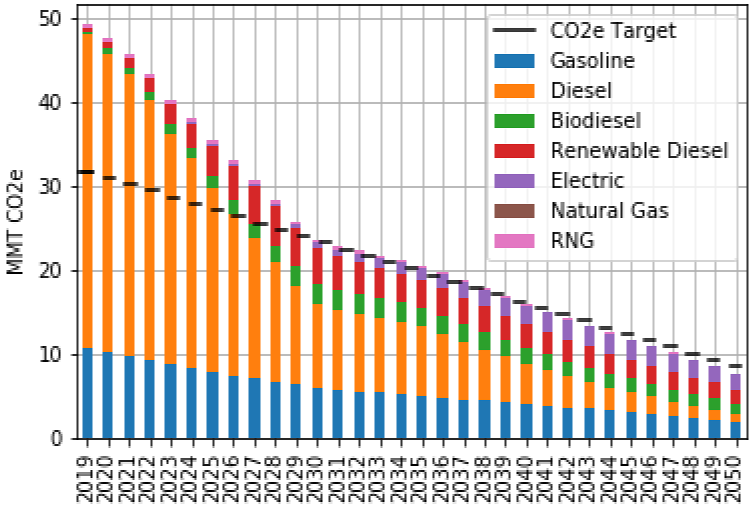


Exhibit 45: Electricity Scenario Vehicle Population by Fuel Type



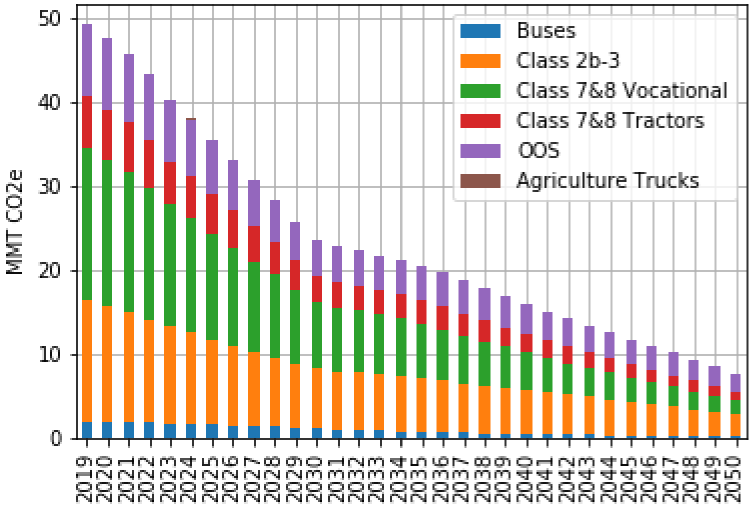
4.3 CO$_2$e Emissions

Exhibit 46: Electricity Scenario GHG Emissions by Fuel Type



4.4 CO$_2$e Emissions by Category

Exhibit 47: Electricity Scenario GHG Emissions by Vehicle Category



4.5 NOx Emissions

Exhibit 48: Electricity Scenario Tailpipe NOx Emissions by Fuel Type

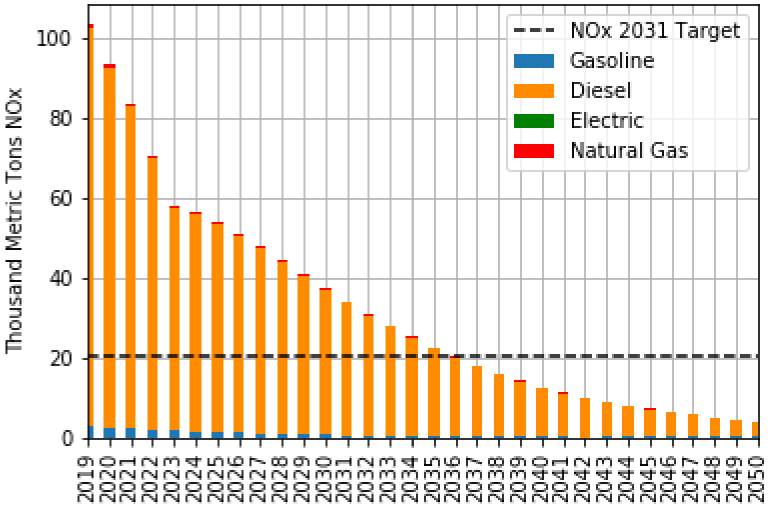
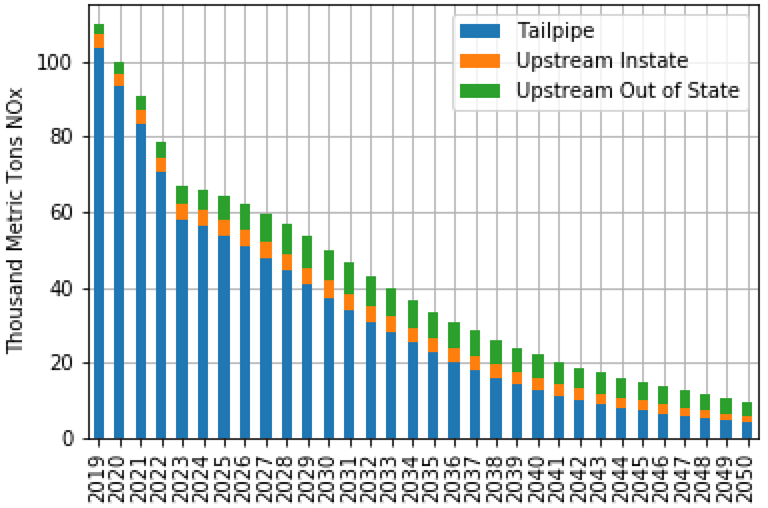


Exhibit 49: Tailpipe vs. Upstream NOx Emissions



4.6 NOx Emissions by Category

Exhibit 50: Electricity Scenario Tailpipe NOx Emissions by Vehicle Category

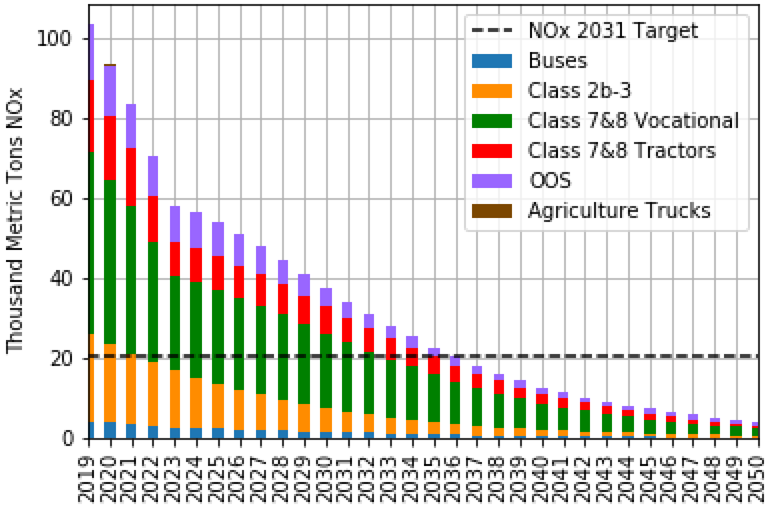
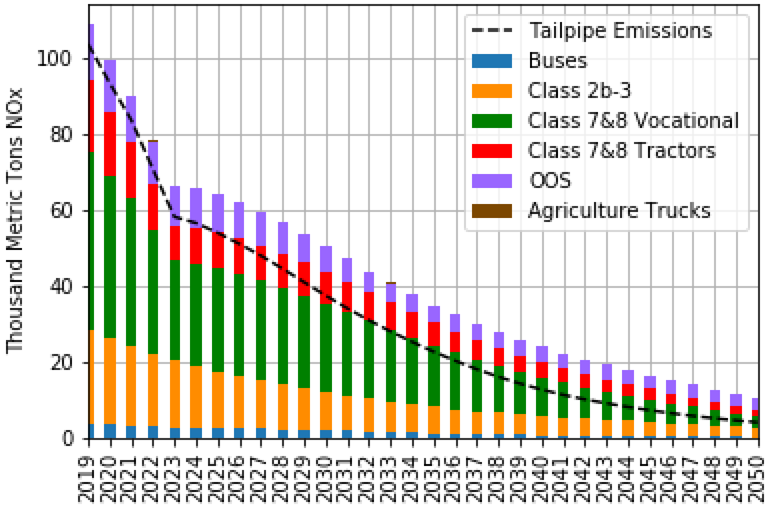


Exhibit 51: Electricity Scenario Lifecycle NOx Emissions by Vehicle Category



4.7 PM2.5 Emissions

Exhibit 52: Electricity Scenario Tailpipe PM2.5 Emissions

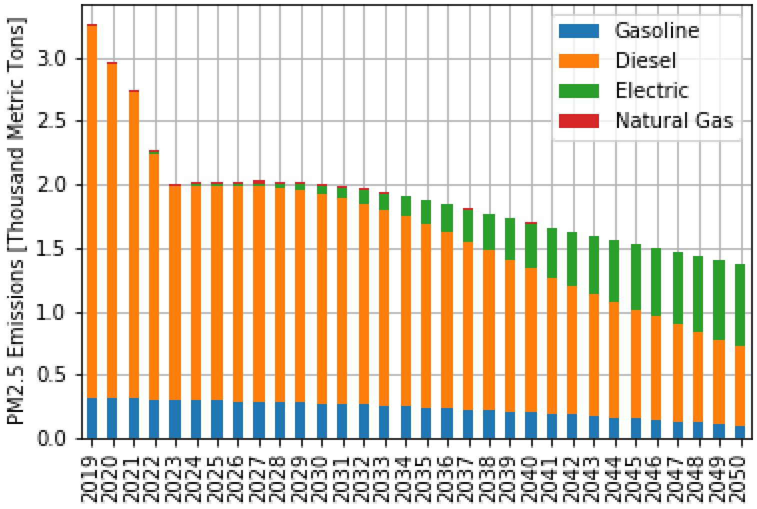
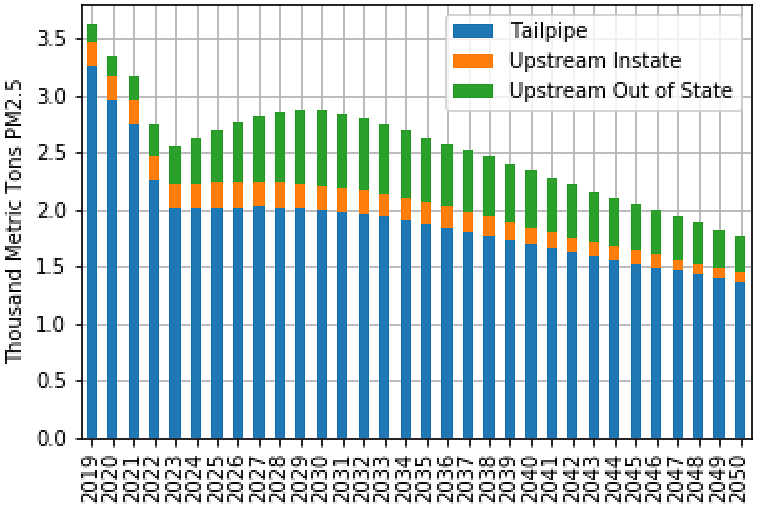


Exhibit 53: Electricity Scenario Tailpipe vs Upstream PM2.5 Emissions



4.8 PM2.5 Emissions by Category

Exhibit 54: Electricity Scenario Tailpipe PM2.5 Emissions by Vehicle Category

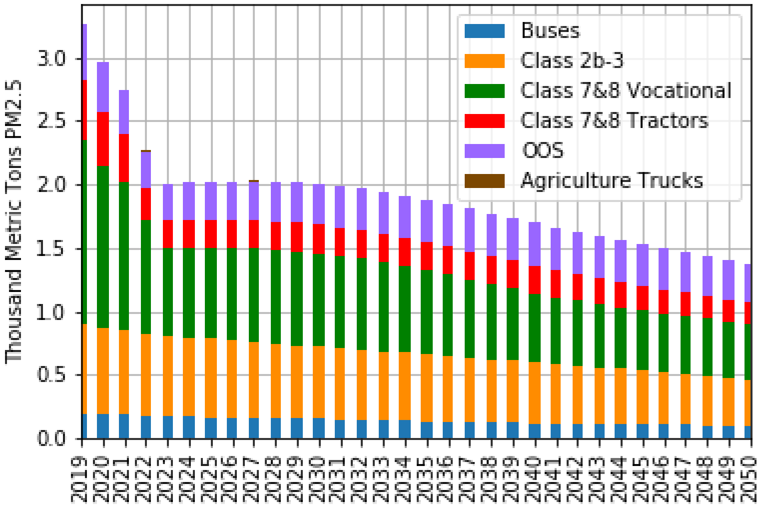
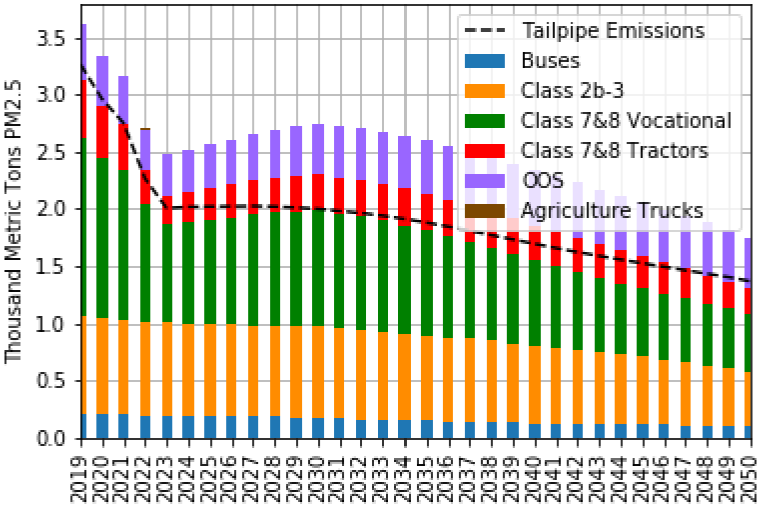
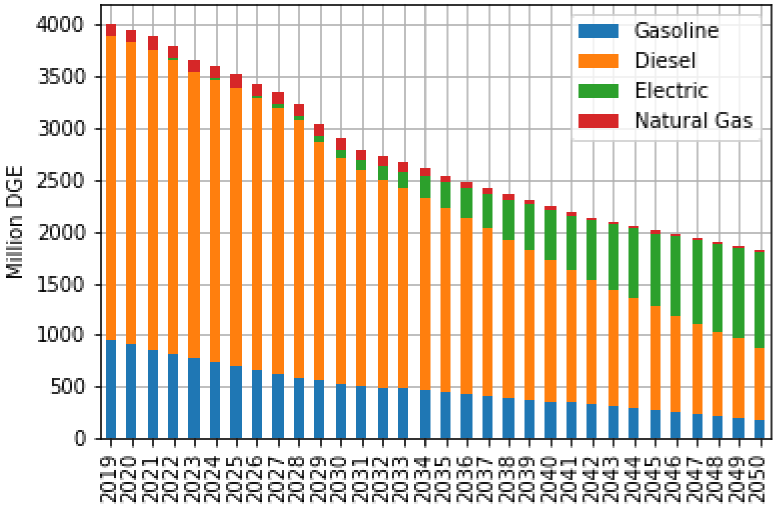


Exhibit 55: Electricity Scenario Lifecycle PM2.5 Emissions by Vehicle Category



4.9 Fuel Consumption

Exhibit 56: Electricity Scenario Fuel Consumption



5. Electricity Max Scenario

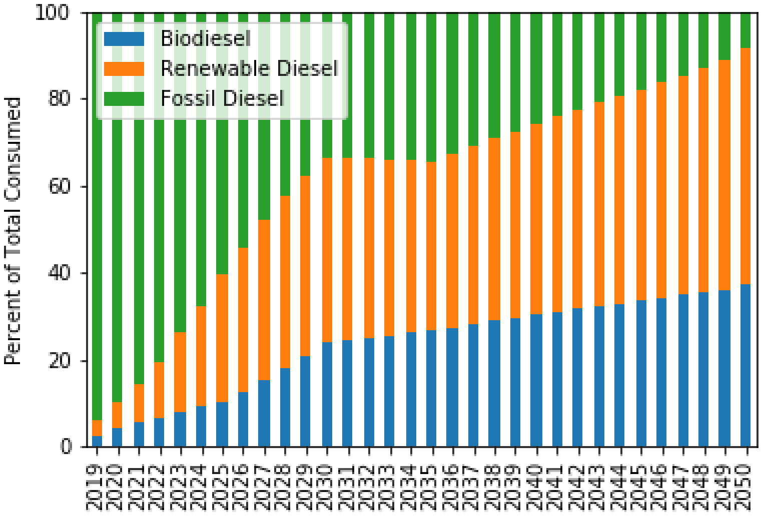
5.1 Electricity Max Scenario Description

The purpose of the Electricity Max scenario is to assess the feasibility of meeting the 2031 NOx target through aggressive electrification of trucks. This scenario presents an upper bound by maximizing the rate of electrification of trucks.

Table V-5: Strategies Included in Electricity Max Scenario

<table>
<tr><th>Strategies Included</th><th>Adjustments Made</th></tr>
<tr><td>Phase 2 GHG Standards</td><td>None</td></tr>
<tr><td>Senate Bill 1 (Truck and Bus Regulation)</td><td>None</td></tr>
<tr><td>Innovative Clean Transit</td><td>Includes all bus EMFAC categories, rather than just urban buses. Now includes: urban bus, school bus, motor coach, other bus, all other buses.</td></tr>
<tr><td>Sustainable Freight Action Plan</td><td>None</td></tr>
<tr><td>San Pedro Bay Ports Clean Air Action Plan</td><td>None</td></tr>
<tr><td>Implementing Low NOx Diesel Engines</td><td>None</td></tr>
<tr><td>Further Tightening of Phase 2 GHG Standards Beyond 2027</td><td>Out-of-state fuel economy improvement to 20% by 2050</td></tr>
<tr><td>Advanced Technology Deployment</td><td>Assumed all new sales are BEVs
100% of new sales electric vehicles by 2024
<table>
<tr><th>Model Year</th><th>Class 2B-3</th><th>Class 4-8 Vocational</th><th>Class 7-8 Tractors</th></tr>
<tr><td>2024 and beyond</td><td>100%</td><td>100%</td><td>100%</td></tr>
</table></td></tr>
<tr><td>Zero-Emission Airport Shuttle Regulation</td><td>100% of fleet electric by 2025, rather than 2035</td></tr>
<tr><td>Out-of-State Truck Requirement</td><td>Assumed BEVs
Out-of-state electric vehicle sales beginning in 2020
100% of out-of-state vehicle sales electric vehicles by 2024</td></tr>
</table>

Exhibit 57: Electricity Max Scenario Diesel Blend



5.2 Vehicle Profile

Exhibit 58: Electricity Max Scenario Vehicle Sales by Fuel Type

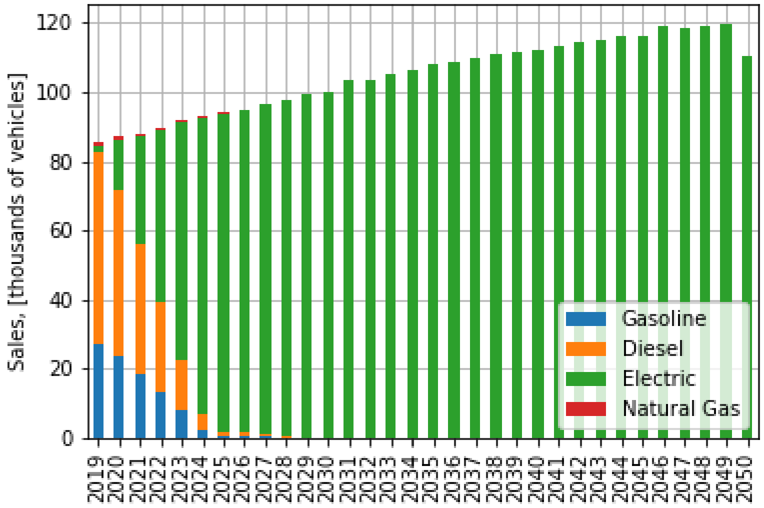
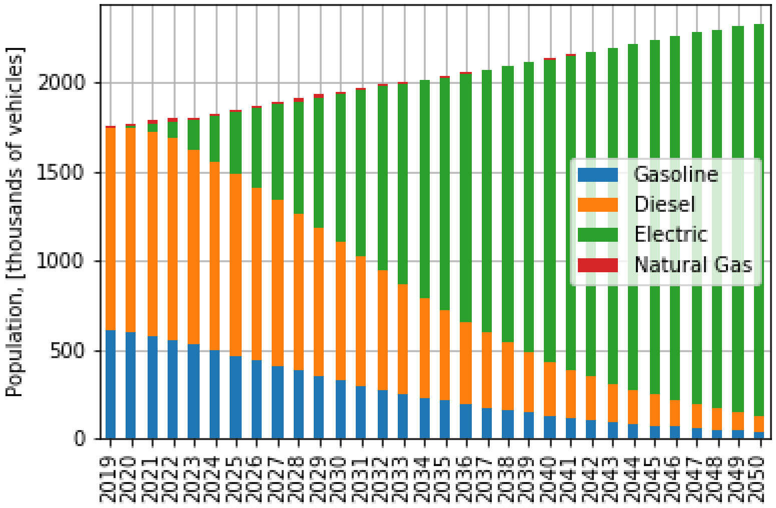
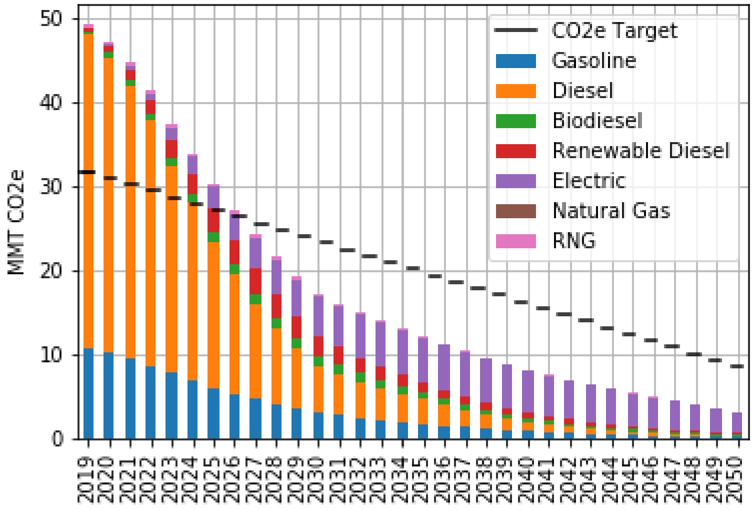


Exhibit 59: Electricity Max Scenario Vehicle Population by Fuel Type



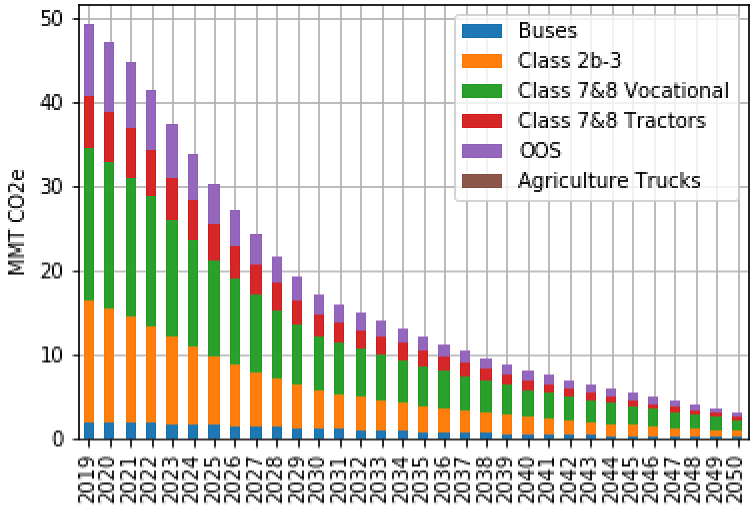
5.3 CO_2e Emissions

Exhibit 60: Electricity Max Scenario GHG Emissions by Fuel Type



5.4 CO_2e Emissions by Category

Exhibit 61: Electricity Max Scenario GHG Emissions by Vehicle Category



5.5 NOx Emissions

Exhibit 62: Electricity Max Scenario Tailpipe NOx Emissions by Fuel Type

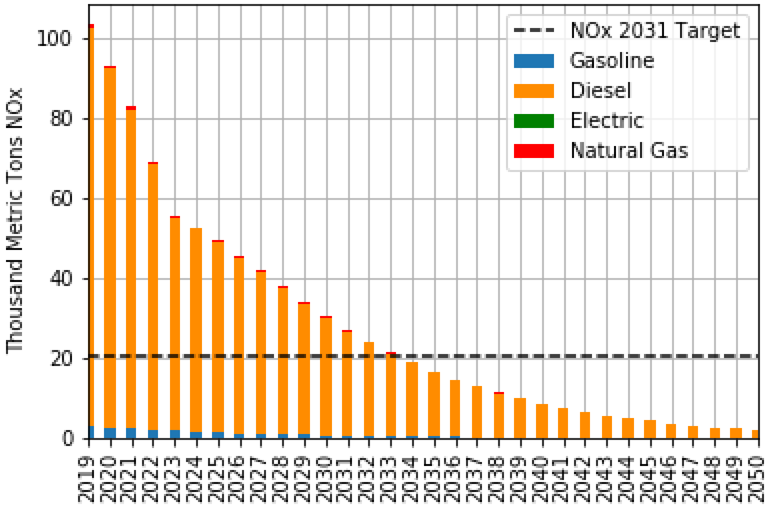
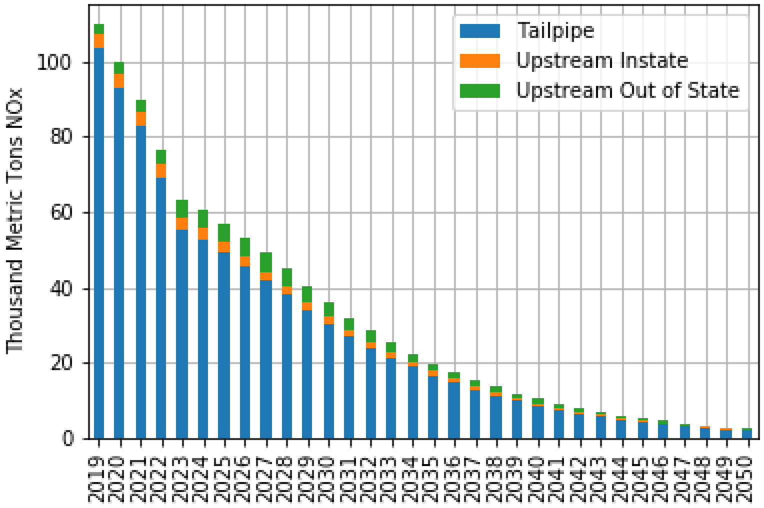


Exhibit 63: Electricity Max Scenario Tailpipe vs. Upstream NOx Emissions



5.6 NOx Emissions by Category

Exhibit 64: Electricity Max Scenario Tailpipe NOx Emissions by Vehicle Category

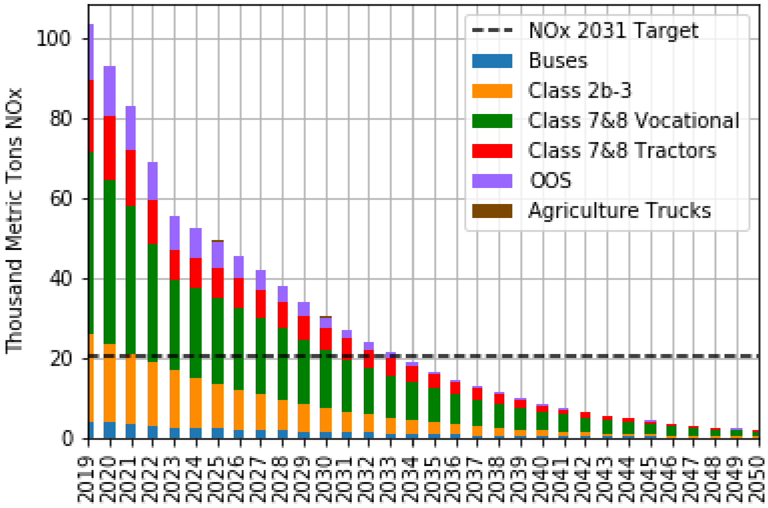
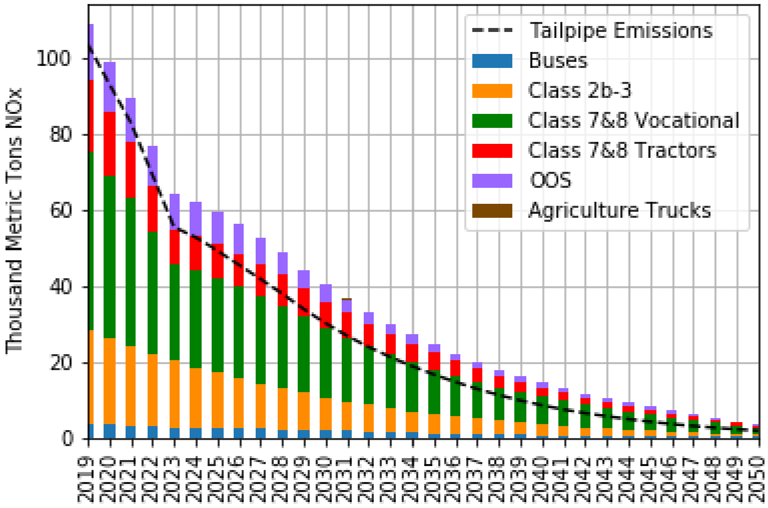


Exhibit 65: Electricity Max Scenario NOx Emissions by Vehicle Category



5.7 PM2.5 Emissions

Exhibit 66: Electricity Max Scenario Tailpipe PM2.5 Emissions

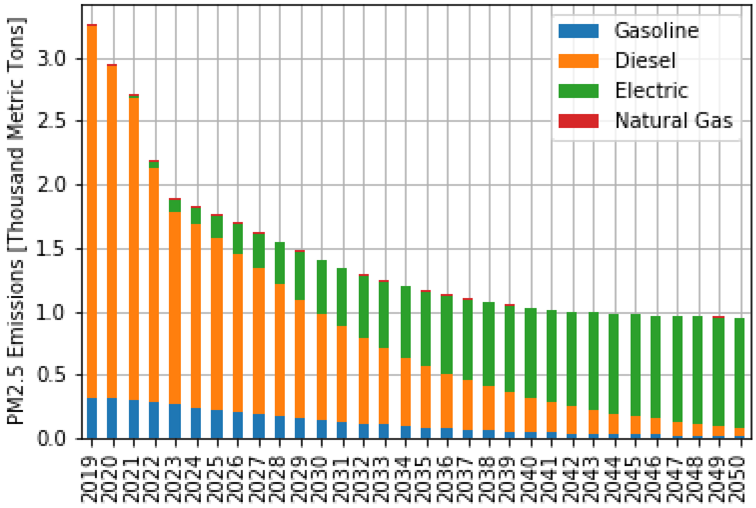
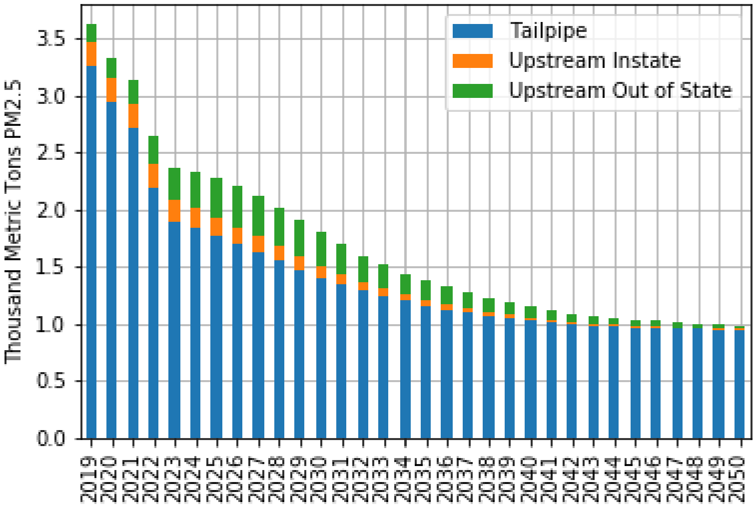


Exhibit 67: Electricity Max Scenario Tailpipe vs. Upstream PM2.5 Emissions



5.8 PM2.5 Emissions by Category

Exhibit 68: Electricity Max Scenario Tailpipe PM2.5 Emissions by Vehicle Category

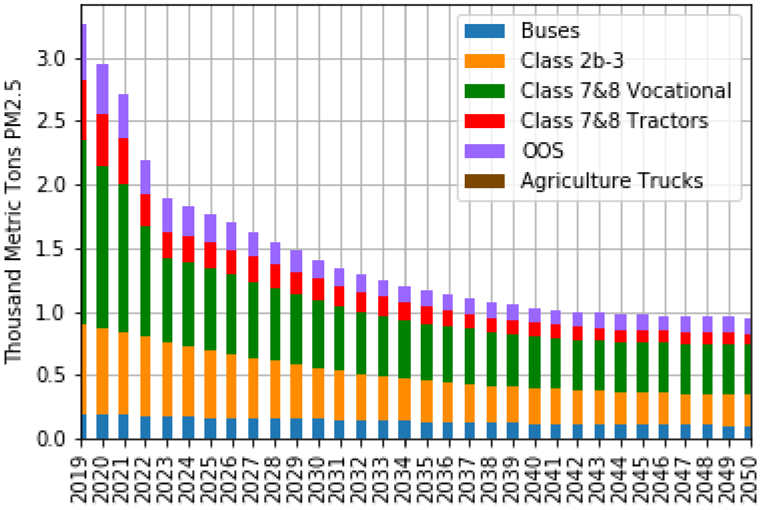
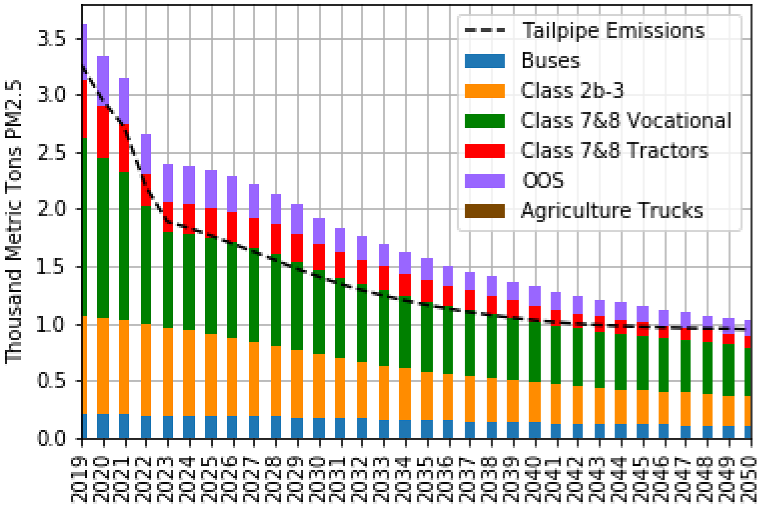
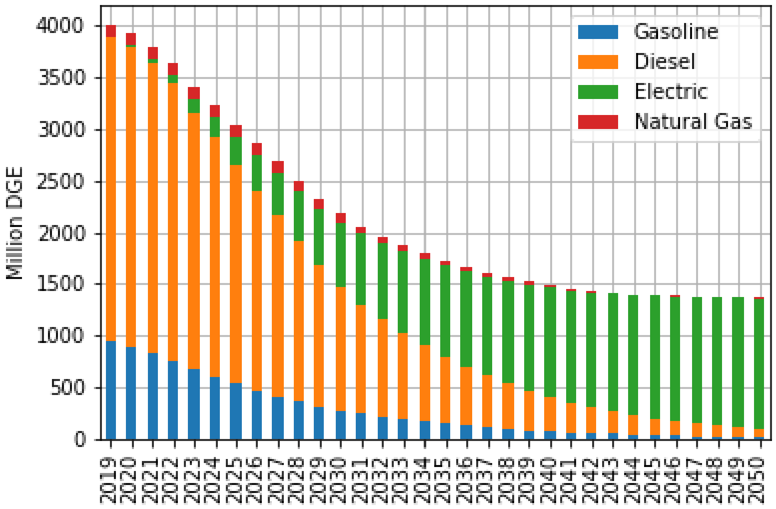


Exhibit 69: Electricity Max Scenario Lifecycle PM2.5 Emissions by Vehicle Category



5.9 Fuel Consumption

Exhibit 70: Electricity Max Scenario Fuel Consumption



VI. Appendix B - References

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Comparison of Medium- and Heavy-Duty Technologies in California

Part 2

Total Cost of Ownership Technology Analysis

December 2019

Submitted by:
ICF
75 East Santa Clara Street
Suite 600
San Jose, CA 95113

Prepared For:
California Electric Transportation Coalition
Natural Resources Defense Council

In Partnership With:
Union of Concerned Scientists
Earthjustice
BYD
Ceres
NextGen Climate America

With Advisory Support From:
University of California, Davis Policy Institute for Energy, Environment and the Economy
East Yard Communities for Environmental Justice

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Abbreviations and Acronyms

ANL	Argonne National Laboratory
CARB	California Air Resources Board
CEC	California Energy Commission
CI	carbon intensity
CNG	compressed natural gas
DGE	diesel gallon equivalents
DOE	U.S. Department of Energy
EV	electric vehicle
gCO_2/MJ	grams of CO2 per megajoule
GHG	greenhouse gas
GVWR	gross vehicle weight rating
HD	heavy duty
HDV	heavy-duty vehicle
HVIP	Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project
ICCT	International Council on Clean Transportation
ICT	innovative clean transit
IOU	investor owned utility
kWh	kilowatt hour
LADWP	Los Angeles Department of Water and Power
LCFS	Low Carbon Fuel Standard
LFG	landfill gas
LH	long haul
MD	medium duty
MD/HD	medium and heavy duty
NZE	near zero emission
NO_x	oxides of nitrogen
OEM	original equipment manufacturers
PG&E	Pacific Gas and Electric
RFS	Renewable Fuel Standard
RNG	renewable natural gas
SCAQMD	South Coast Air Quality Management District
SCE	Southern California Edison
SDG&E	San Diego Gas and Electric
SH	short haul
TCO	Total cost of ownership
VMT	vehicle miles traveled

I. Purpose

This portion of the report assesses the total cost of ownership (TCO) of medium and heavy-duty (MD/HD) technologies. The TCO as calculated here is the cumulative cost to the first owner of the vehicle, including vehicle capital (purchase price minus residual value), operation and maintenance (which includes the cost of fuel), and any necessary infrastructure, minus applicable incentives and regulatory requirements. The TCO was performed for various vehicle sizes from Class 2b to Class 8 trucks and buses, and across fuels including diesel, natural gas and renewable natural gas (including Landfill Gas (LFG)), electricity, and hydrogen. This report is divided into the following sections:

- TCO Methodology
- TCO Results
- TCO Conclusions

Throughout the report, MD/HD trucks are on-road vehicles with a gross vehicle weight rating (GVWR) of over 8,500 lbs., also known as Class 2b-8 vehicles. In some of the tables, the report further divides the HD category into heavy and medium categories. In this context, heavy-heavy duty trucks include class 7 and class 8 vehicles that are over 26,000 lbs. GVWR. Medium HD trucks are class 4-6 trucks that fall between a GVWR range of 14,001 and 26,000 lbs. GVWR. Each vehicle weight category (Class 4-5, Class 6-7, and Class 8) also is divided into short-haul (SH) and long-haul (LH), based on the daily miles traveled. This breakout is especially important with battery electric trucks that can have variable battery pack sizes.

II. TCO Methodology

Having a lower TCO for alternative fuels compared to conventional fuels from a first-owner/operator perspective is essential for the long-term success and deployment of these vehicles. The analysis was performed for current conditions and 2030, when vehicle prices for electrified technologies have decreased to become comparable with conventional vehicles. The TCO is from the perspective of a first owner/operator and includes the following elements:

- Vehicle Cost
- Operations and Maintenance
- Infrastructure
- Incentives (i.e., HVIP, LCFS, and utility programs)

ICF quantified the estimated TCO for each of the vehicle classes on a net present value basis in 2019 dollars using a 5% discount rate. The “current” analyses are 2019 dollars in 2019 and the “2030” analyses are 2019 dollars in 2030. The following sections review the individual methodologies for calculating the four cost categories in the TCO. The fuels and technologies compared include diesel, diesel hybrid (transit bus only), battery electric, natural gas, and hydrogen. Due to a lack of data on plug-in hybrid electric trucks, they were not included in the comparison, and hydrogen trucks were compared in only a few classes.

1. Vehicle Cost

The vehicle cost is made up of two elements: initial vehicle price and residual value. This analysis looks at the TCO from the perspective of the first owner, who will sell the vehicle and recoup a certain portion of the initial vehicle price. The initial vehicle prices are broken up into two sections (buses and trucks) due to the differences in the price estimation methodologies.

1.1 Initial Vehicle Price

Buses

ICF relied on bus prices and future price projections developed during the rulemaking process for the California Air Resources Board (CARB) Innovative Clean Transit measure[1] for all bus categories including diesel, diesel hybrid, natural gas, electric, and hydrogen. ICF had extensive conversations with electric transit bus manufacturers, who concluded that while the current electric bus prices might have slightly changed from the publication of the Innovative Clean Transit (ICT) analysis, they agreed with the relative price comparison across the technologies and the future price forecasting. For electric buses, ICF started with current bus prices and applied the ICT annual price projections. Table II-1 shows the 2019 initial purchase prices for buses.

Table II-1. 2019 Bus Initial Purchase Price Assumptions in 2019$

	Diesel	Diesel Hybrid	Electric	Natural Gas	Hydrogen
Transit Bus	$476,000	$691,000	$753,000	$544,000	$1,100,000
Articulated Bus	$887,000	1,087,000	$1,200,000	$952,000	N/A
School Bus A	$100,000	$150,000	$275,000	$130,000	N/A
School Bus C	$105,000	N/A	$300,000	$135,000	N/A

Table II-2 shows the initial purchase prices for buses in 2030 after applying price projection factors for each individual technology from the ICT analysis. In 2030, the prices of electric transit and school buses are forecasted to still be higher than the prices of diesel and natural gas.

Table II-2. 2030 Bus Initial Purchase Price Assumptions in 2019$

	Diesel	Diesel Hybrid	Electric	Natural Gas	Hydrogen
Transit Bus	$615,000	$830,000	$784,000	$685,000	$808,000
Articulated Bus	$1,172,000	$1,328,000	$1,190,000	$1,223,000	N/A
School Bus A	$132,000	$198,000	$290,000	$167,000	N/A
School Bus C	$139,000	N/A	$316,000	$173,000	N/A

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[1] CARB, 2017a

Trucks

For conventional fueled diesel and low-NOx natural gas trucks, ICF started with current truck prices from both the California Energy Commission Revised Transportation Energy Demand Forecast 2018-2030[2] and an extensive literature review performed by ICF.[3] Since Cummins-Westport has transitioned completely to low-NOx 8.9L engines, the assumption was made that all natural gas engines will transition to low-NOx, and the pricing will hold for these engines.

Similar to natural gas and diesel trucks, battery electric price projections start with current truck prices. The projection methodology differs from conventional trucks by separating the battery and balance of truck price and applying separate cost reduction curves and factors to each portion of the truck. Also, since in each vehicle weight category there are varying duty cycles, a short-haul and long-haul vehicle price was determined with differing battery sizes and balance of truck.

Alternative Vehicle Pricing Models

Vertically integrated battery and vehicle manufacturers have the potential to lower costs compared to OEMs, which must purchase full battery packs or battery cells.

The starting point for the current 2019 battery electric truck prices for Classes 4-8 is an extensive literature review by ICF[4] and conversations with current battery electric truck manufacturers. Since many Class 6-8 electric trucks are currently imported from China, the prices supplied by the manufacturers include a 25% tariff on the cost (not price). ICF assumed a 20% profit on trucks to estimate the tariff and isolate the non-tariff price of the truck. No tariff amount is assumed in Class 4/5 truck prices because a significant portion of these trucks are produced in the United States.[5] For Class 2b and 3 battery electric truck prices, ICF utilized the short-haul Class 4/5 truck price for Class 3 trucks and applied a 25% cost reduction to account for the reduced workload of a Class 2b truck compared to Class 3 trucks.

Many original equipment manufacturers (OEMs), including Volvo, Daimler, Cummins, and Tesla, plan to manufacture trucks in the United States and would therefore avoid tariffs. In addition, BYD has communicated that increases in truck demand and resulting production volume would lead to moving truck manufacturing to the United States.

For the Class 8 hauling categories, ICF developed a simplified hydrogen truck pricing assumption with hydrogen trucks having the same relative price to electric trucks as hydrogen buses to electric buses. Table II-3 shows the initial purchase price assumptions for each of the truck categories after removing the estimated cost of tariffs on the electric trucks. For natural gas, incremental cost is $10,000 for Class 2b, $15,000 for Class 3, $20,000 for Class 4/5, $30,000-32,000 for Class 6-8; if 11.9L engines are used, ICF estimated a $30,000 additional incremental cost. For refuse trucks, the cost is only for the truck portion, not the back power takeoff system.

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[2] CEC, 2018

[3] ICF, 2018

[4] Ibid.

[5] The workhorse electric Class 4/5 stepvan developed for UPS has an estimated price of $133,000 and a 130 kWh battery pack which places the cost squarely in between the short-and long-haul Class 4/5 prices.

Table II-3. 2019 Truck Initial Purchase Price Assumptions in 2019$

	Diesel	Electric	Natural Gas[6]	Hydrogen
Class 2b	$27,500	$75,000 (75 kWh)	$37,500	N/A
Class 3	$39,000	$100,000 (100kWh)	$54,000	N/A
Class 4/5 Short-Haul	$48,000	$100,000 (100kWh)	$68,000	N/A
Class 4/5 Long-Haul	$48,000	$150,000 (150 kWh)	$68,000	N/A
Class 6/7 Short-Haul	$63,000	$167,000 (150 kWh)	$95,000	N/A
Class 6/7 Long-Haul	$63,000	$250,000 (250 kWh)	$95,000	N/A
Class 8 Short-Haul	$110,000	$250,000 (250 kWh)	$140,000	$400,000
Class 8 Long-Haul	$160,000	$375,000 (500 kWh)	$190,000	$480,000
Refuse[7]	$150,000	$352,500	$180,000	N/A

To project future prices, ICF applied the Bloomberg New Energy Finance price curves to the current estimated truck battery pack price of $375/kWh. The forecast estimates a 58% price reduction from 2019 to 2030 in constant dollars. To extract CEC's assumed balance of truck cost reductions ICF used the California Energy Commission (CEC) Revised Transportation Demand Forecast[8] for electric trucks, with an assumed 200 kWh battery pack for Class 6 trucks. The result is an estimated 37% decrease in the price of the balance of truck from 2019 to 2030. Appendix A – Vehicle Price Forecast includes all of the details, calculations, and methodology for the vehicle pricing. Table II-4 shows the 2030 initial purchase prices for trucks in 2019$. Again, cost for the refuse truck does not include the back power takeoff system.

---

[6] $10,000 incremental cost for Class 2b, $15,000 for Class 3, $20,000 for Class 4/5, $30,000-32,000 for Class 6-8; if 11.9L engines are used, estimated $30,000 additional incremental cost

[7] Cost is only for the truck portion, not the back PTO system.

[8] CEC, 2018

Table II-4. 2030 Truck Initial Purchase Price Assumptions in 2019$

	Diesel	Electric	Natural Gas	Hydrogen
Class 2b	$28,700	$40,000	$38,700	N/A
Class 3	$40,700	$53,000	$55,700	N/A
Class 4/5 SH	$51,000	$53,000	$71,000	N/A
Class 4/5 LH	$51,000	$80,000	$71,000	N/A
Class 6/7 SH	$66,000	$90,000	$98,000	N/A
Class 6/7 LH	$66,000	$133,000	$98,000	N/A
Class 8 SH	$118,000	$133,000	$147,000	$137,000
Class 8 LH	$172,000	$191,000	$200,000	$197,000
Refuse[9]	$160,000	$191,000	$190,000	N/A

The results of the cost analysis are similar to the results of the analysis performed by the California Air Resources Board (CARB) for regional Class 8 tractors ($425,000 in 2018, $232,000 in 2024, and $196,000 in 2030).[10] In all truck categories, the battery electric truck prices decreased by 40-50% in 2019 dollars. Taking inflation into account, the projected price decreases range between 35 and 40%. In 2030, electric trucks are forecasted to remain more expensive than diesel trucks.

During the course of interviews with OEMs and stakeholders, ICF learned that some diesel truck manufacturers and dealers want to include operations and maintenance for the vehicles within the sales contract. This allows the dealer to make money off the continued service and potentially lower the price of the vehicle below the vehicle-only market rate. In addition, OEMs discussed potential rebound effects in vehicle prices resulting from larger battery packs. The lower per kWh battery prices could result in the demand for and production of electric trucks with larger battery packs resulting in constant or potentially increasing electric truck prices. This analysis is based on consistent vehicle configurations.

1.2 Residual Value

Based on conversations with OEMs ICF estimated the residual value to be 40% of the initial purchase price for diesel and natural gas vehicles. With battery electric truck prices projected to decrease, the quantified residual value in this analysis was relative to the less expensive new electric truck at the time of resale. ICF developed a formula in consultation with battery electric truck OEMs that quantified the residual value of the total truck by separately quantifying the battery and balance of truck portion within the residual value. The residual value of the electric truck is a combination of 40% of the balance of truck for new trucks at the time of resale plus 40% of 80% of the value of the battery for new electric trucks at the time of resale. The 20%

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[9] Cost is only for the truck portion, not the back PTO system.

[10] CARB, 2019a

reduction in the battery portion of the formula is to account for the estimated 20% loss of battery capacity during the first-owner operation.

The residual value is considered a payment in the TCO and is deducted, in net present value, from the initial vehicle price to quantify the total vehicle cost. Residual value is not included in the refuse, school bus, and transit vehicle categories because these vehicles are utilized in their respective fleets for their full vehicle life.

2. Infrastructure Costs

The TCO analysis includes infrastructure costs (capital, and operation and maintenance), allocated on a per-vehicle basis. The analysis assumes the existing conventional fuel infrastructure is sufficient, and therefore excludes infrastructure costs for gasoline and diesel trucks.

2.1 Capital Costs

Electric Charging

The electric charger and installation costs are based on a combination of data from CARB's ICT rulemaking,[11] CARB's Advanced Clean Truck rulemaking and filings in the California Public Utility Commission's ISB 350 proceedings,[12] the ICF literature review, and conversations with OEMs. Table II-5 shows the charger and installation costs ICF used in the analysis.[13] The charger and installation costs identified are the costs to the vehicle owner and do not include costs to the utility.

Table II-5. Electric Charger and Installation Costs in 2019$

Charger Capacity	Charger Cost	Installation Cost
19 kW	$5,000	$20,000
40 kW	$8,000	$20,000
100 kW	$40,000	$48,000
200 kW	$50,000	$55,000

In the TCO analysis, ICF assumed two vehicles per charger, and capital costs are allocated to vehicles based on the cost per year per vehicle and first-owner vehicle life.

Natural Gas Station

ICF, through the literature review process, estimated the natural gas vehicle station cost for fast-fill refueling.[14] Table II-6 shows the natural gas station equipment and installation costs assuming 50% of the cost is for equipment and 50% for installation.

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[11] CARB, 2017a

[12] CARB, 2019b

[13] There is the potential for certain truck use cases to utilize much higher power levels per charger, which will result in higher costs for higher capacity chargers.

[14] DOE, 2014. Used as the basis for infrastructure costs in the AFLEET tool.

Table II-6. Natural Gas Station Costs in 2019$

Station Capacity	Station Equipment Cost	Installation Cost
1 million DGE/year	$1,000,000	$1,000,000

The calculation of the cost per vehicle per year for natural gas fueling stations employed a 50% capacity factor as an estimate of the amount of time a fast fill station would be utilized during the 20-year lifetime of the station.

Hydrogen Station

The hydrogen station cost was estimated using formulas within the Alternative Fuel Life-Cycle Environmental and Economic Transportation (AFLEET) tool developed by Argonne National Laboratory (ANL) for a 230 kg/day facility.[15] The total station cost in the analysis is $2.5 million as shown in Table II-7. ICF reviewed additional documentation and found that CARB approximated a total capital cost of $2.4 million for a 180 kg/day gaseous delivered station and $2.8 million for a 350 kg/day liquid delivered station.[16]

Table II-7. Hydrogen Station Costs in 2019$

Station Capacity	Total Station Cost
230 kg/day	$2,500,000

The station costs were allocated to vehicles by developing cost per year per vehicle factors for each vehicle and duty type based on the cost, capacity, and annual fuel consumption per vehicle and assuming a 20-year lifetime of the station. The calculated costs per year per vehicle were multiplied by the first-owner vehicle life to determine allocated infrastructure cost per vehicle.

2.2 Station O&M Costs

ICF utilized the assumptions contained within the AFLEET tool[17] to develop the annual station operations and maintenance costs. Table II-8 shows the station operations and maintenance costs used within the analysis.

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[15] ANL, 2018

[16] CARB, 2017b

[17] ANL, 2018

Table II-8. Station Annual Operations and Maintenance Costs in 2019$

Station Type	Annual Operations and Maintenance
19 kW	$500
40 kW	$800
100 kW	$4,000
200 kW	$5,500
Diesel Station	$5,000
Natural Gas Station	$115,000
Hydrogen Station	$152,000

3. Fuel Prices

3.1 Non-Electricity Fuel Prices

The fuel prices for gasoline, diesel, and hydrogen were based on the prices in the CEC Revised Transportation Demand Forecast.[18] The prices for conventional fuels include not only the cost or crude oil and refining, but also the cost of compliance with carbon regulations including cap-and-trade and the LCFS. The result is that conventional fuel prices increase over time. For compressed natural gas (CNG), ICF created fleet CNG prices based on data from the Alternative Fuel Data Center[19] for private station CNG prices, combined with the CEC price forecasts and previous analysis performed by ICF for CNG prices. Since the prices are from the perspective of the vehicle owner, both fossil CNG and CNG using renewable natural gas (RNG) purchased from the pipeline have the same commodity price resulting in the same price forecast. Any additional value for RNG would come from the LCFS as discussed in Section 5.2.

ICF assumed that the value from the LCFS and Renewable Fuel Standard (RFS) will result in the price of biodiesel, and renewable diesel being the same as the price of diesel. This means that vehicle operators that use biodiesel and renewable diesel do not generate any additional revenue from the environmental attributes of the fuels.

CEC price forecasts are available only through 2030. For fuels other than hydrogen ICF continued the fuel pricing trends through 2042 to model the 2030 cases, as shown in Figure II-1. Based on the current costs of hydrogen, the use of pipeline gas via steam reformation as the major production technology for hydrogen, and the costs of natural gas and electricity for compression, ICF assumed the hydrogen fuel price would level out at $8/diesel gallon equivalent (DGE), or approximately $7.14/kg. This is similar to the $6/kg price goals for hydrogen from HD vehicle manufacturers such as Nikola.[20]

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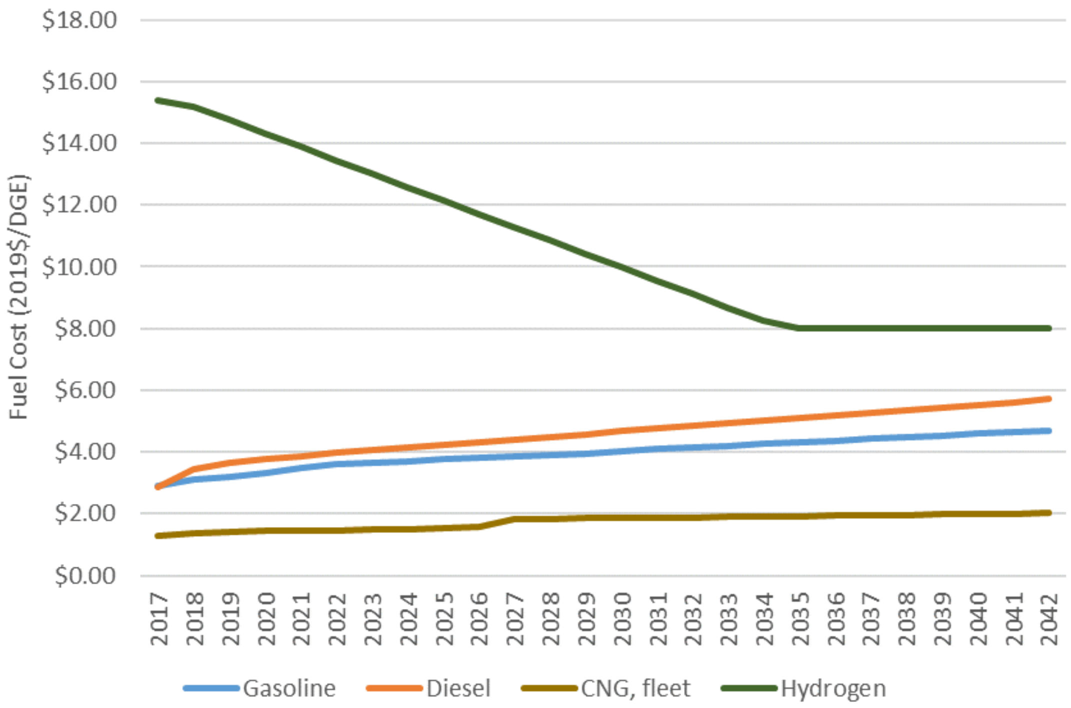
[18] CEC, 2018

[19] DOE AFDC, 2018

[20] Cannon, 2019

Figure II-1. Gasoline, Diesel, CNG, and Hydrogen Fuel Prices in 2019$



3.2 Electricity Rates

ICF used existing and upcoming electric vehicle (EV) rate structures combined with duty-specific load profiles to quantify the effective electricity rate each year for Los Angeles Department of Water and Power (LADWP), Pacific Gas and Electric (PG&E), Southern California Edison (SCE) and San Diego Gas and Electric (SDG&E). The effective electricity rates were weighted based on 2017 supplied electricity.[21] Table II-9 shows the utility rate structures used in the analysis and the weighting factor applied to develop an effective statewide electricity rate. Details on these rate structures can be found in Appendix B – TCO Details by Vehicle Segment.

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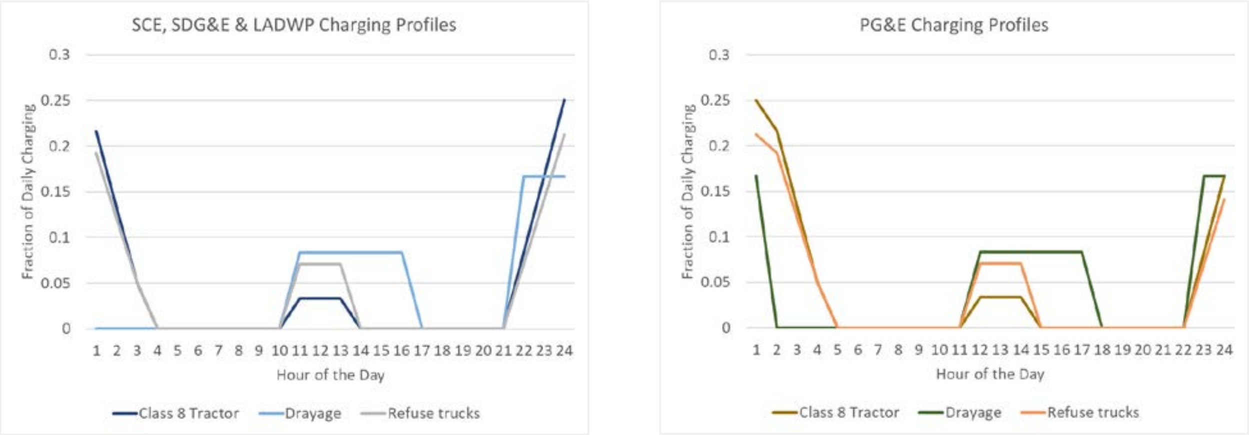
[21] CEC, 2019

Table II-9. Utility Electricity Rate Structure and California Weighting

Utility	Rate Structure	California Weighting Factor
LADWP	TOU A-2(B)[22]	11.0%
PG&E	Proposed EV-Large[23]	39.5%
SCE	TOU EV-8[24][25]	40.5%
SDG&E	EV-TOU[26]	9.0%

ICF started with previously developed load profiles[27] and made modifications to account for average daily electricity consumption, charger load, and vehicles primarily charging at off-peak periods to minimize fuel costs. The newly developed load profiles consider two vehicles utilizing one charger and chargers utilizing their full load. Figure II-2 shows the load profiles for Class 8 tractors, drayage, and refuse trucks. PG&E has a separate load profile due to its off-peak period starting an hour later than LADWP, SCE, and SDG&E. The remaining vehicle segment load profiles can be found in Appendix B – TCO Details by Vehicle Segment.

Figure II-2. Class 8 Tractor, Drayage, and Refuse Load Profiles



The SCE MD/HD rate structures are unique in that demand charges are incorporated into the energy prices for the first five years and then separate demand charges are phased back in for years six through eleven. Since SCE identified electricity rates in nominal dollars projected out to 2030, ICF discounted the future rates using an inflation rate of 1.9%. For all other electricity rates, the assumption was made that electricity rates would only increase by the rate of inflation resulting in constant prices in 2019 dollars. Figure II-3 shows the resulting effective electricity

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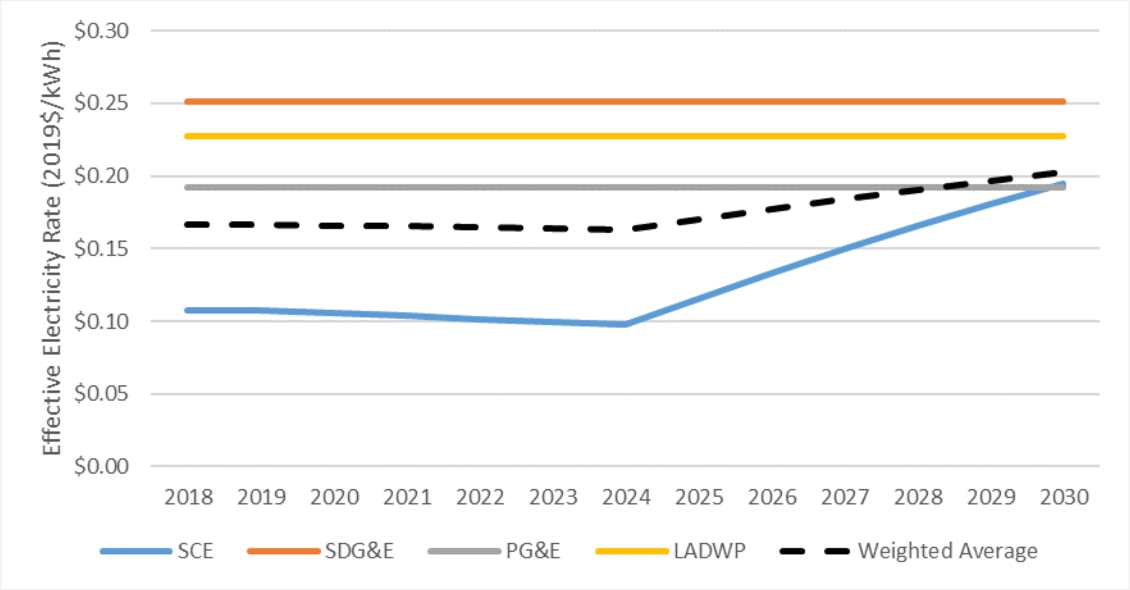
[22] LADWP, 2017
[23] PG&E 2019
[24] SCE, 2019
[25] SCE TOU-9 could be a relevant rate schedule for higher capacity chargers and larger sites.
[26] SDG&E, 2017t the time of the analysis the new SDG&E rate structures had not been approved
[27] ICF, 2016

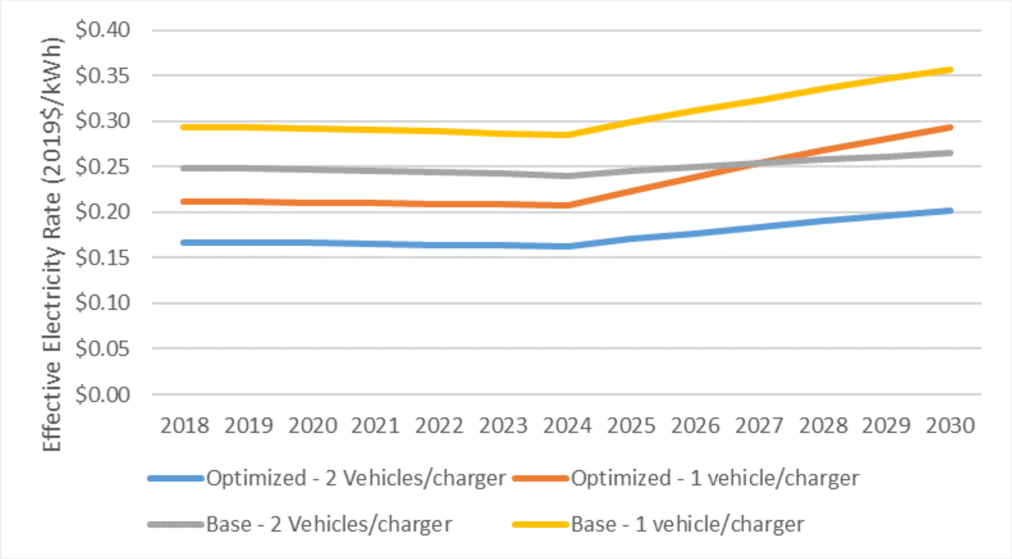
rates for drayage trucks based on the load profiles shown in Figure II-2 and demand charges from the 200 kW charger.

Figure II-3. Class 8 Drayage Effective Electricity Rates



The two main assumptions—the number of vehicles per charger and the time when charging occurs—are extremely important in quantifying the electricity fuel costs for each vehicle and duty cycle. ICF ran scenarios for one and two vehicles per charger and charging beginning at the end of the workday (5-6 p.m.) and at the beginning of the off-peak period. Figure II-4 shows the California weighted average effective rate comparison between base charging (starting at 5-6 p.m.), optimized charging (evening and daytime charging occurring around low- or off-peak rates) and one or two vehicles per charger.

Figure II-4. Effective California Average Electricity Rate Comparison



SCE Demand Neutralization

Going forward, for existing collocated EV accounts, SCE has a program of demand neutralization where if the EV charging load is less than the facilities-related demand (FRD) of the primary services account, then no separate FRD is charged for the qualifying EV account. Use of demand neutralization for qualifying accounts would result in lower electricity rates than those presented in Figure II-3 for drayage trucks.

The TCO analysis utilizes the optimized charging with 100% charger load and two vehicles per charger. ICF believes that fleet owners will want to minimize their electricity cost, which will result in charging moving to low- or off-peak periods and avoiding the highest electricity rate and demand charge periods. Also, based on the assumption that chargers will operate at 100% of their load, two vehicles were able to fully charge overnight on one charger in all applications. Fleets will look to lower their infrastructure costs and only install one charger for two vehicles. If a fleet throttled the load of the chargers to around 50% and employed one vehicle per charger, it would result in the same effective electricity rate as two vehicles per charger utilizing the full charger load.

The analysis in Figure II-4 quantifies an uncertainty in the cost of charging EVs where the costs of charging could increase by 70-80% over what is used in the analysis. In almost all cases, this still results in a lower TCO for EVs compared to diesel and natural gas.

3.3 Fuel Consumption

Table II-10 shows the annual vehicle miles traveled (VMT), vehicle first-owner life, baseline diesel fuel economy, and ratios used to calculate fuel economy for alternative fuels. ICF used the reported energy economy ratios (EERs)[28,29] to convert the diesel fuel economy to electric, natural gas, or hydrogen fuel economy, in DGE. For example, the EV fuel economy in DGE is equal to the diesel fuel economy in DGE multiplied by the EV EER. The values in the table are aggregated from multiple sources including the AFLEET[30] tool and the ICF literature review.[31]

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[28] CARB, 2018a

[29] The EERs utilized are for the current state of technology. Since EERs are relative, technologies outpacing each other in fuel economy advancements would result in changes to EERs in future years.

[30] ANL, 2018

[31] ICF, 2018

Table II-10. VMT, First Owner Life, Diesel Fuel Economy, and EERs

Vehicle Duty Cycle/Type	VMT (mi/yr)	First Owner Life (yrs)	Diesel FE (mi/DGE)	Electric EER	Natural Gas EER	Hydrogen EER
Class 2b Van	25,000	10	18	3.4	1	
Class 3 Walk-In	25,000	7	15	3.4	1	
Class 4-5 Shuttle	30,000	12	8.9	4.2	0.9	
Class 4-5 Urban Delivery	35,000	7	11.1	4.2	0.9	
Class 6 Urban Delivery	30,000	7	8.8	5	0.9	
Class 6 Regional Haul	35,000	7	8.9	5	0.9	
Class 8 Refuse	13,000	12	2.2	5	0.9	
Class 8 SH	50,000	7	6.63	5	0.9	1.9
Class 8 Tractor	85,000	5	5.9	5	0.9	1.9
Class 8 Drayage	45,000	7	6.0	5	0.9	1.9
Transit Bus	34,000	12	4.51	5	0.9	1.9
Articulated Bus	34,000	12	3.0	5	0.9	1.9
School Bus A & C	11,200	12	7.91	5	0.9	–

4. Vehicle Maintenance Costs

ICF relied on data from the AFLEET tool for vehicle maintenance costs.[32] The only modification, based on consultation with OEMs, was to reduce operations and maintenance costs by 50% for electric trucks in 2030. In many cases, hydrogen maintenance costs were not included in the AFLEET tool. As a result, ICF used the same values as electric trucks for Class 8 trucks and articulated buses. Table II-11 shows the vehicles maintenance costs in the TCO analysis.

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[32] ANL, 2018

Table II-11. Vehicle Maintenance Cost (2019$/mi.)

Vehicle Duty Cycle/Type	Diesel	Electric	Natural Gas	Hydrogen
Class 2b Van & 3 Walk-In	0.31	0.21	0.23	–
Class 4-5 Shuttle	0.26	0.19	0.23	–
Class 4-5 Urban Delivery	0.20	0.16	0.22	–
Class 6 Urban Delivery	0.19	0.17	0.21	–
Class 6 Regional Haul	0.19	0.17	0.19	–
Class 8 Refuse	2.89	2.83	2.91	–
Class 8 SH & Tractor	0.19	0.17	0.19	0.17
Class 8 Drayage	0.20	0.17	0.22	0.17
Transit Bus	0.79	0.60	0.85	1.16
Articulated Bus	0.86	0.65	0.93	0.65
School Bus A & C	0.94	0.87	0.95	–

5. Incentives

The incentives category includes policy and/or funding mechanisms that decrease the TCO. The three policies and/or incentives included in the analysis are the Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP), the Low Carbon Fuel Standard (LCFS), and the California Investor Owned Utility (IOU) Programs for charging infrastructure. The analysis does not include other incentive programs including the Carl Moyer Program[33],CARB Low Carbon Transportation grants, California Energy Commission Clean Transportation Program[34] grants, and Proposition 1B. The Moyer program mainly funds vehicle replacements and repowers/conversions with vouchers for scrapping and replacing older, higher polluting vehicles earlier than would have been expected through normal attrition or by regulation. The TCO calculations include residual value. As a result, including Carl Moyer vouchers, which require scrappage, would offset the residual value resulting in zero net benefit to the TCO. In addition, the Carl Moyer Program includes state funding caps, project lifetime requirements, and unique air district requirements that limit any additional benefits over HVIP. For example, the South Coast Air Quality Management District (SCAQMD) requires that all on-road projects be operated within its jurisdiction at least 75% of the time. The only vehicles that could potentially see benefits through Moyer are school buses due to the highest funding caps, but the overall funding level for Moyer is much less than HVIP. With the incentive amount per bus, few electric

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[33] Carl Moyer Memorial Air Quality Standards Attainment Program, https://ww2.arb.ca.gov/our-work/programs/carl-moyer-memorial-air-quality-standards-attainment-program

[34] Also known as the Alternative and Renewable Fuels and Vehicle Technology Program

bus projects would be implemented through the Moyer program. At worst, Moyer will have a minimal effect on the statewide deployment of low-emitting vehicles and, at best, will make the estimates presented here a conservative lower bound estimate of actual impacts.

5.1 HVIP – Vehicle

ICF included the 2018-2019 HVIP rebate amounts for electric trucks and buses, hydrogen trucks and buses, and natural gas engines. The following tables show the HVIP incentive amounts for various types of trucks and buses. Table II-12 shows the 2018-2019 truck incentive amounts, and the additional incentive amounts for disadvantaged communities. The TCO analysis only includes the base HVIP voucher amount.[35]

Table II-12. 2018-2019 HVIP Truck Incentive Amounts (2019$)[36]

Truck/Bus Type	GVWR (lbs)	HVIP Voucher	Additional Disadvantaged Community Amount
Electric Class 2b	8,501 – 10,000	$25,000	$5,000
Electric Class 3	10,001 – 14,000	$50,000	$5,000
Electric Class 4-5	14,001 – 19,500	$80,000	$10,000
Electric Class 6	19,501 – 26,000	$90,000	$10,000
Electric Class 7	26,001 – 33,000	$95,000	$15,000
Electric Class 8	>33,000	$150,000	$15,000
Hydrogen Fuel Cell Truck	–	$300,000	$15,000
Natural Gas – 8.9L	–	$45,000	–
Natural Gas – 11.9L	–	$45,000	–

Table II-13 shows 2018-2019 bus and shuttle incentive amounts, and the additional incentive amounts for disadvantaged communities.

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[35] For electric and hydrogen vehicles, there are options for voucher enhancements that were not included in this analysis. These enhancements include additional voucher funding for exportable power (e.g., vehicle to grid capability), extended warranties, and inductive charging.

[36] CARB, 2018b + Low NOx Incentives: Effective 6/6/2019, Low NOx vouchers for new vehicles are $45,000. Repowers for the L9N eligible engine qualify for a $50,000 voucher and repowers with the ISX12N eligible engine qualify for a $52,000 voucher https://www.californiahvip.org/

Table II-13. 2018-2019 HVIP Shuttle and Bus Incentive Amounts (2019$)[37]

Bus/Shuttle Type	Length (ft.)	HVIP Voucher	Additional Disadvantaged Community Amount
Electric Transit	20-24	$80,000	$10,000
Electric Transit	25-29	$90,000	$10,000
Electric Transit	30-39	$120,000	$15,000
Electric Transit	40-59	$150,000	$15,000
Electric Articulated Transit	60	$175,000	$15,000
Hydrogen	>40	$300,000	$15,000
Electric School A	GVWR 10,001-14,000 lb.	$55,000	$5,000
Electric School C	GVWR 16,001-26,000 lb.	$150,000	$10,000
Electric Shuttle Class 4-5	GVWR 14,001-19,000 lb.	$80,000	$10,000

5.2 LCFS

The LCFS allows electric charging, natural gas, and hydrogen station owners to generate credits from using electricity, renewable natural gas, and hydrogen in their vehicles. This analysis assumes that the LCFS credits for renewable liquid fuels are utilized to price these fuels equal to petroleum-based fuels. Table II-14 shows the carbon intensities used in the TCO analysis.

Table II-14. Carbon Intensities for LCFS Crediting

Fuel	Carbon Intensity (gCO2e/MJ)
Electricity – 2019	93.75[38]
Electricity – 2030 (50% Renewables)	71.65
RNG – LFG	40
Hydrogen – LFG	100

For RNG, ICF chose to use the landfill gas (LFG) carbon intensity. For long-term LCFS estimation, there is an uncertain future for the extremely low carbon intensities being approved for animal manure and other waste pathways. As CARB moves to increase the stringency of regulations to reduce emissions from sources covered under California Senate Bill 1383,[39] the long-term potential for generating extremely low CI credits is unknown. Once CARB sets

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[37] Ibid.

[38] The 2019 LCFS carbon intensity for electricity has been updated to 81.49 g/MJ.

[39] California Senate Bill 1383 Short Lived Climate Pollutants looks to reduce methane emissions from dairies and disposal of organic waste. One potential use for this methane is the transportation sector. When the avoided methane emissions are included in the carbon intensity, the result is a negative carbon intensity.

emissions reduction regulations for these waste feedstocks, the carbon intensities for those pathways will revert the carbon intensities closer to existing LFG pathways. All CNG scenarios presented in this report are identified as “CNG, LFG” since they are natural gas vehicles fueled with CNG sourced from landfills.

EV fleet and station owners are able to retain and monetize 100% of the credits generated when utilizing home base fleet charging. RNG and hydrogen fleet and station owners are able to retain and monetize only a small portion of the credits generated. The largest portions of credits are retained by the RNG producer and/or energy marketer. Based upon ICF’s experience in working with the RNG industry, the analysis assumes 10% of the LCFS credits generated are retained by the fleet and station owner. The analysis uses a credit price of $150/credit in 2019$ for all years. For RNG, the analysis assumes 5% of the potential Renewable Identification Number (RIN)[40] value from the RFS program is retained by the fleet and station owner. Currently, electricity and hydrogen used as a transportation fuel cannot generate RINs.

5.3 Utility Program – Infrastructure

Through their individual SB350 Transportation Electrification filings, the California IOUs are proposing to use ratepayer funds to help pay for the build out of MD/HD fleet charging infrastructure. Based upon the applications submitted by PG&E and SCE, ICF included within the analysis a utility program infrastructure incentive of 50% of the charger capital cost. Since the analysis is based on two vehicles for one charger, the incentive per vehicle is valued at 25% of the charger cost. This incentive is included in the 2019 analysis but not in the 2030 analysis. The analysis focused on the utility programs from the three major IOUs, which supply approximately 65% of the electricity sold in California. SDG&E recently had its program approved. Between the IOUs and the Public Owned Utilities, a patchwork of incentives covers nearly the entire State of California.

III. TCO Results

This section provides the results of the TCO analysis for each vehicle type and duty cycle. The results are divided into GVWR segments and vehicle types including Class 8, Class 6, Classes 2b-5, Transit Bus and School Bus. All of the natural gas scenarios presented are identified as “CNG, LFG” since they are natural gas vehicles fueled with CNG sourced from landfills.

As shown in Figure III-1, in almost all vehicle segments electric vehicles have the lowest TCO today when available incentives are taken into account, and the lowest TCO in 2030 even without HVIP vehicle purchase incentives. In the 2030 TCO analysis, the lower costs for BEVs are driven both by lower fuel costs and the projected reduction in maintenance costs. LCFS revenue plays an important role in both time periods. Hydrogen trucks, while having the highest TCO in both the current and 2030 results, see a significant TCO reduction in 2030 due to large reductions in vehicle cost and fuel costs.

More information is provided in the discussion of each segment, and detailed results and exact dollar values presented in the figures can be found in

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[40] RIN is a Renewable Identification Number and is the metric and currency of the Renewable Fuel Standard.

Appendix B – TCO Details by Vehicle Segment.

Table III-1. Vehicle Segments Where Electric Vehicles Have the Lowest TCO

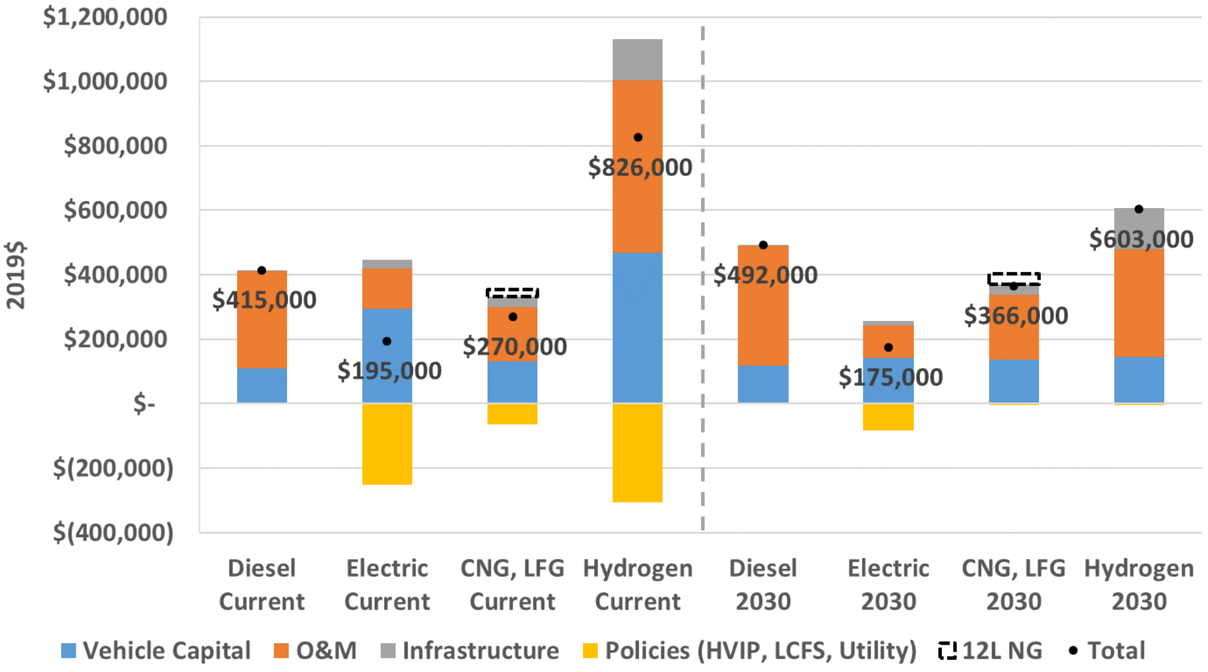
Vehicle Duty Cycle/Type	Lowest Current TCO (with incentives)	Lowest 2030 TCO (without HVIP)
Class 8 Tractor	✓	✓
Class 8 Short Haul	✓	✓
Class 8 Drayage	✓	✓
Class 8 Refuse	✓	✓
Class 6 Regional Haul	✓	✓
Class 6 Urban Delivery	-	✓
Class 4-5 Urban Delivery	✓	✓
Class 4-5 Shuttle	✓	✓
Class 3 Walk-In	✓	✓
Class 2b Van	✓	✓
Transit Bus	✓	✓
Articulated Bus	✓	✓
School Bus A	-	-
School Bus C	✓	-

1. Class 8

1.1 Tractor

Figure III-1 shows results from the Class 8 Tractor TCO analysis. The Class 8 Tractor duty cycle included the highest annual VMT (85,000 mi/yr) and the shortest first-owner life (five years).

Figure III-1. Class 8 Tractor TCO Analysis Results



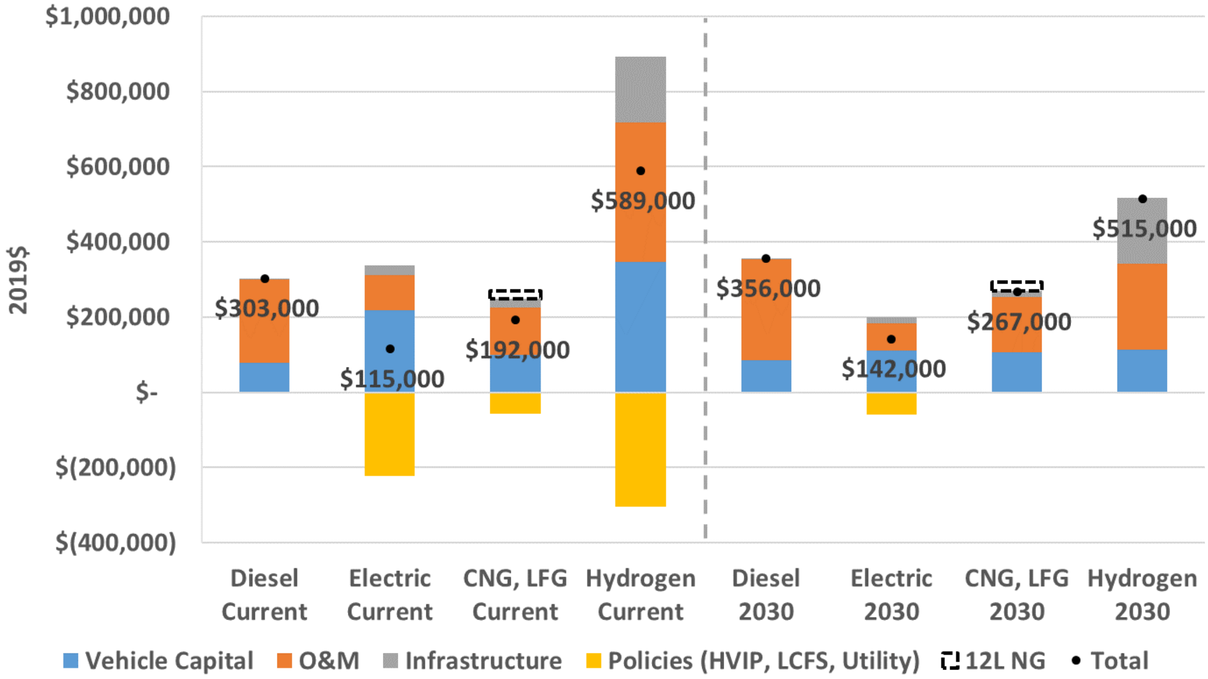
The electric truck has significantly lower O&M costs compared to diesel and natural gas, driven by lower fuel costs. The fuel cost for the electric truck owner, averaged statewide, was approximately $63,000 over the first-owner lifetime, with a range of electricity costs between $53,000 and $105,000 depending on the utility. The analysis also includes what the TCO would be with a 12L Low-NOx natural gas engine compared to a 9L. The incremental TCO difference between the 9L and 12L engines is small.

In 2030, the fuel cost for the electric truck owner, averaged statewide, was approximately $68,000 over the first-owner lifetime, with a range of electricity costs between $65,000 and $105,000 depending on the utility. The maintenance costs also decreased from $64,000 to $32,000 between the current and 2030 cases. Natural gas trucks using LFG had a lower TCO than diesel in both the current and 2030 results.

1.2 Short Haul (SH)

Figure III-2 shows the results of the Class 8 short-haul TCO analysis results. The short-haul duty cycle included a VMT of 50,000 miles and a first-owner life of seven years. The trend of the results is very similar to that of the Class 8 tractor.

Figure III-2. Class 8 SH TCO Analysis Results



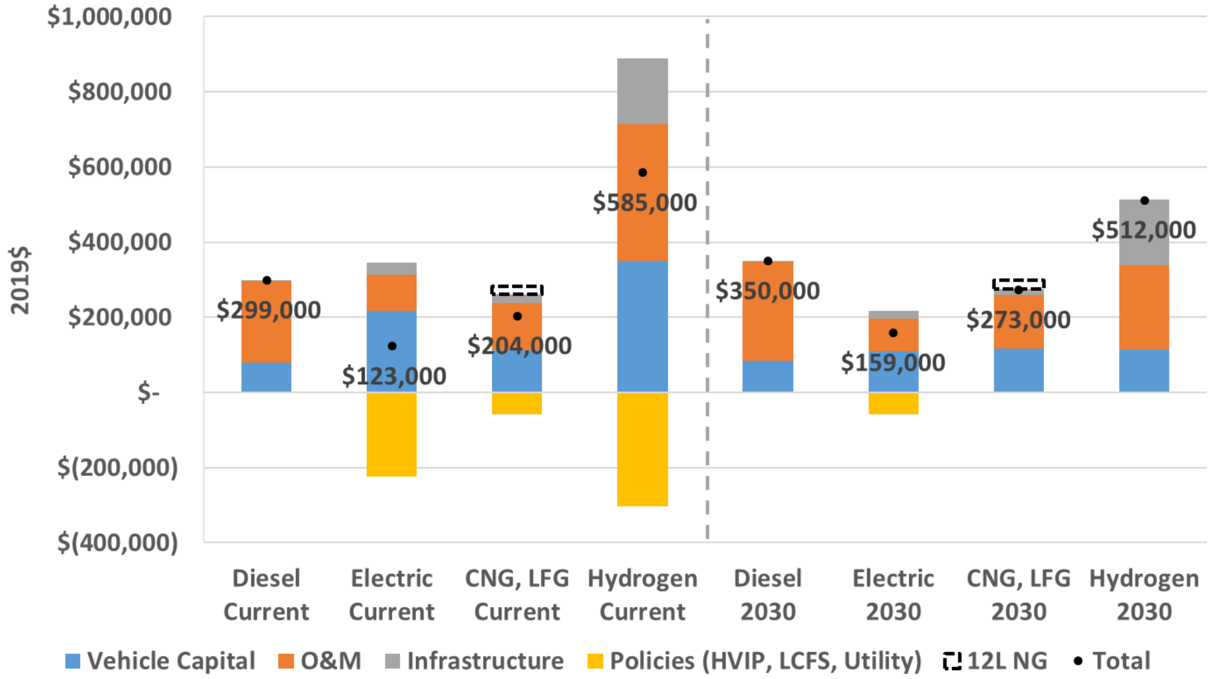
The electric truck has significantly lower O&M costs compared to both diesel and natural gas trucks due to lower fuel costs. The fuel cost for the electric truck owner, averaged over a statewide basis, was approximately $43,000 over the first owner lifetime, with a range of electricity costs between $35,000 and $74,000 depending on the utility.

In the 2030 TCO analysis, the fuel cost for the electric truck owner, averaged statewide, was approximately $47,000 over the first-owner lifetime, with a range of electricity costs between $44,000 and $74,000 depending on the utility. The maintenance costs also decreased from $50,000 to $25,000 between the current and 2030 cases, respectively. Hydrogen trucks, while having the highest TCO in both the current and 2030 results, see a significant TCO reduction due to large reductions in vehicle cost and fuel costs. Natural gas trucks using LFG consistently had a lower TCO than diesel trucks.

1.3 Drayage

Figure III-3 shows the results of the Class 8 drayage TCO analysis. The Class 8 drayage analysis assumed an annual VMT of 45,000 mi/yr and an associated 10% reduction in fuel economy as compared to short-haul tractors. The results for short-haul and drayage are very similar.

Figure III-3. Class 8 Drayage TCO Analysis Results



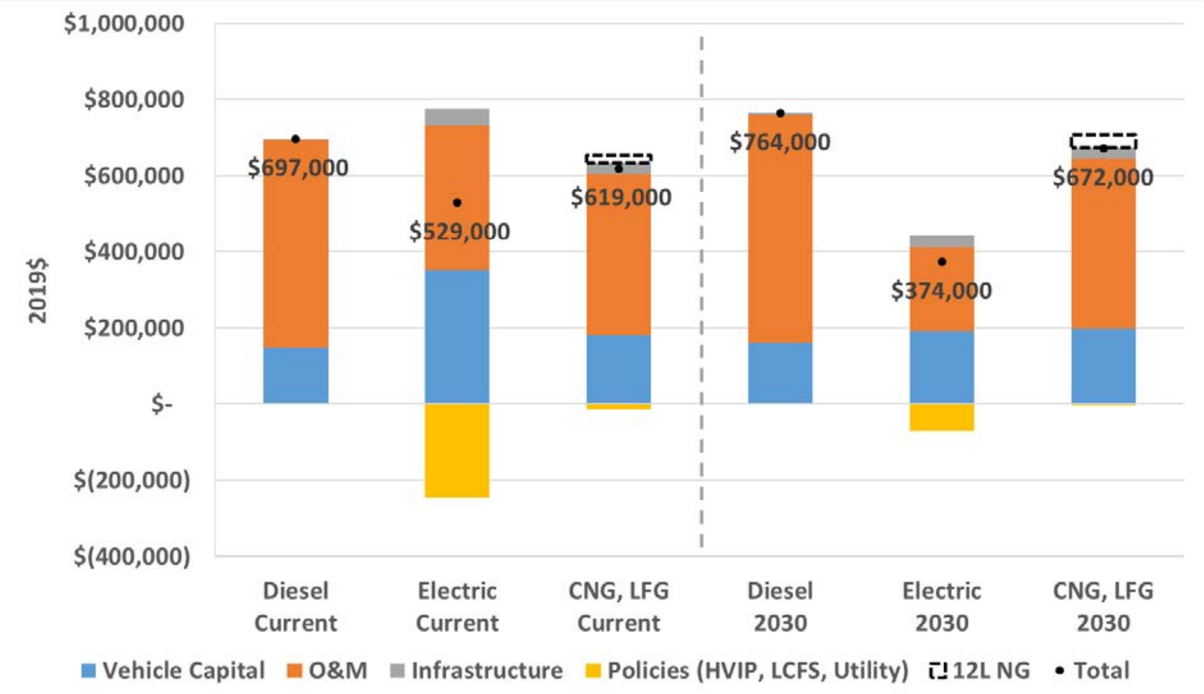
The current fuel cost for the electric truck owner, averaged statewide, was approximately $50,000 over the first-owner lifetime, with a range of electricity costs between $32,000 and $77,000 depending on the utility. The larger range of electric fuel costs for drayage compared to short-haul is due to the load profile, which includes charging during the middle of the day.

In the 2030 TCO analysis, the fuel cost for the electric truck owner, averaged statewide, was approximately $62,000 over the first-owner lifetime, with a range of electricity costs between $59,000 and $77,000 depending on the utility. The maintenance costs also decreased from $45,000 to $22,500 between the current and 2030 cases, respectively.

1.4 Refuse

Figure III-4 shows the results of the Class 8 refuse truck TCO analysis. Refuse trucks have very low annual VMT (13,000 mi/yr), full vehicle life with the first owner (12 yrs) and a very low baseline fuel economy (2.2 mi/DGE).

Figure III-4. Class 8 Refuse Truck TCO Analysis Results



The results for the various refuse truck technologies are much closer to each other than the other Class 8 duty cycles, largely because refuse trucks are assumed to remain with the first owner for their entire 12-year vehicle life. The fuel cost for the electric truck owner, averaged statewide, was approximately $53,000, with a range of electricity costs between $44,000 and $89,000 depending on the utility.

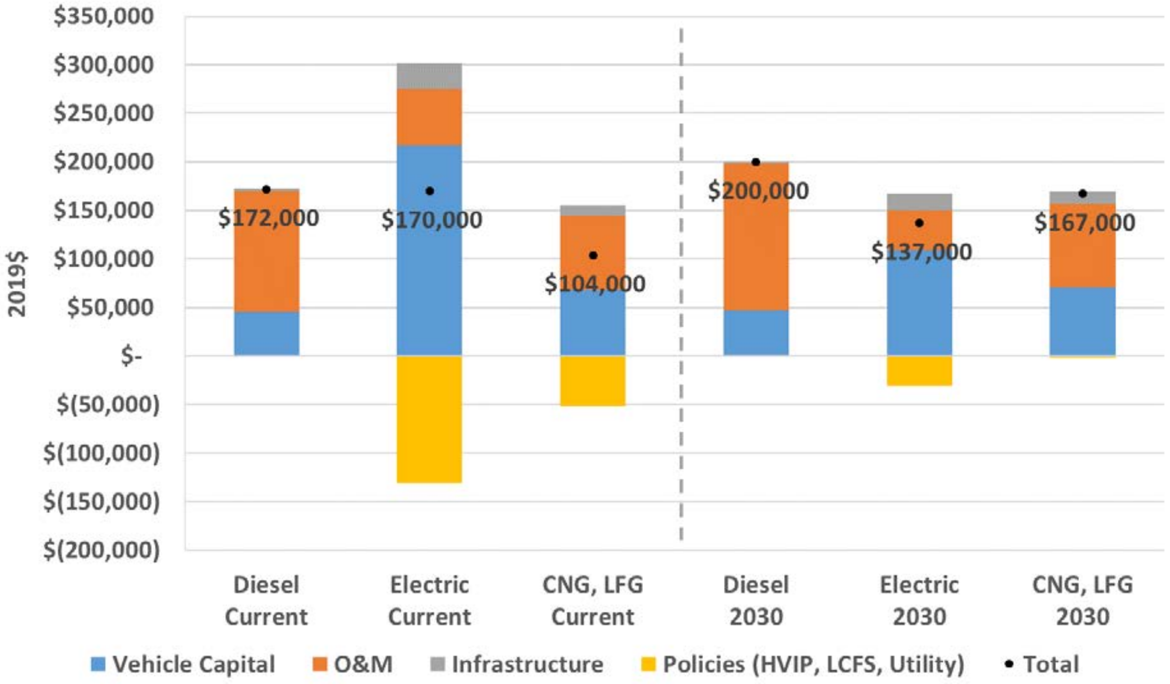
In the 2030 TCO analysis, the fuel cost for the electric refuse truck owner, averaged statewide, was approximately $57,000, with a range of electricity costs between $53,000 and $89,000 depending on the utility. The maintenance costs also decreased from $326,000 to $163,000 based on the assumption that maintenance costs per mile for electric trucks would reduce by 50% from current to 2030.

2. Class 6

2.1 Regional Haul

Figure III-5 shows the results of the TCO analysis for Class 6 regional haul trucks. The Class 6 regional haul analysis included an annual VMT of 35,000 miles and a first-owner life of 7 years.

Figure III-5. Class 6 Regional Haul TCO Analysis Results



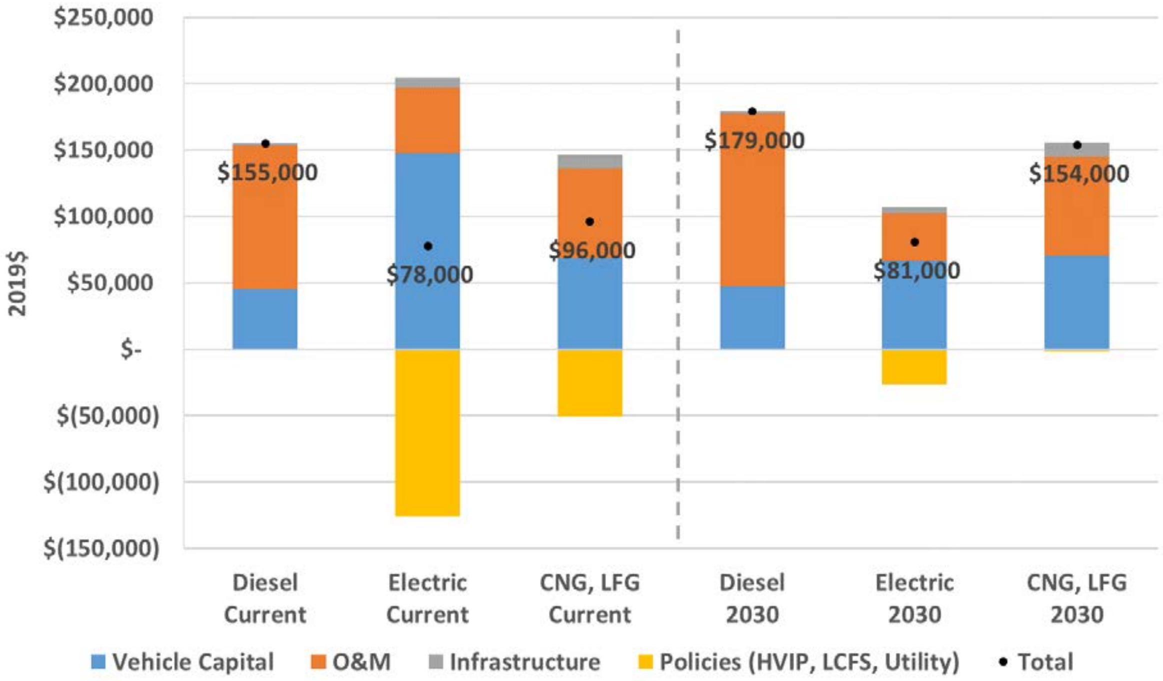
The analysis of current TCO shows that for Class 6 regional haul the CNG, LFG vehicles have the lowest current TCO. Electric trucks with HVIP and other incentives have a similar TCO compared to diesel. The electric truck has lower O&M costs compared to diesel and natural gas. The fuel cost for the electric truck owner, averaged statewide, was approximately $22,000 over the first-owner lifetime, with a range of electricity costs between $18,000 and $38,000 depending on the utility.

In 2030, the fuel cost for the electric truck owner, averaged statewide, was approximately $23,000 over the first-owner lifetime, with a range of electricity costs between $21,000 and $38,000 depending on the utility. Maintenance costs decreased from $35,000 to $17,500 based on the assumption that maintenance costs per mile for electric trucks would reduce by 50% from current to 2030.

2.2 Urban Delivery

Figure III-6 shows the Class 6 urban delivery TCO analysis results. The Class 6 urban delivery analysis included an annual VMT of 30,000 miles and a first-owner life of 7 years.

Figure III-6. Class 6 Urban Delivery TCO Analysis Results



The main difference between the Class 6 urban delivery and regional haul applications is the battery size selected for each duty cycle. The urban delivery TCO included a 150 kWh battery pack while the regional haul TCO analysis included a 250 kWh battery pack. This results in an increased vehicle cost of $83,000 for the regional haul electric truck. The fuel cost for the electric truck owner, averaged statewide, was approximately $20,000 over the first-owner lifetime, with a range of electricity costs between $17,000 and $32,000 depending on the utility.

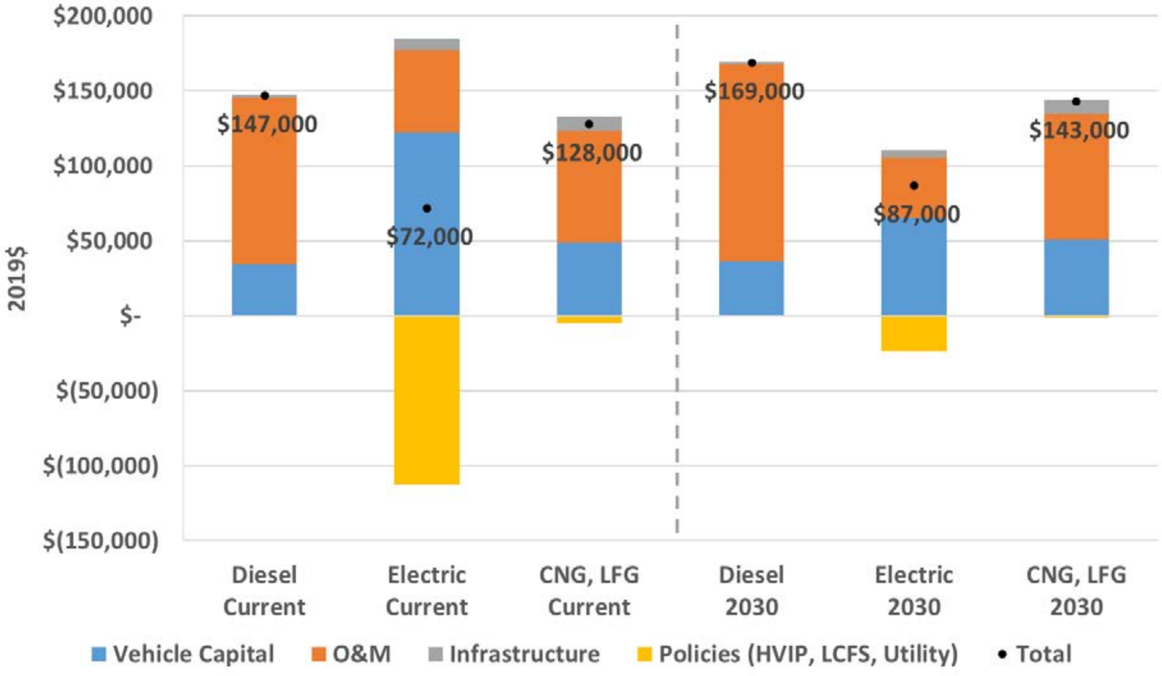
In the 2030 TCO analysis, the fuel cost for the electric truck owner, averaged statewide, was approximately $21,000 over the first-owner lifetime, with a range of electricity costs between $20,000 and $32,000 depending on the utility. Maintenance costs decreased from $30,000 to $15,000.

3. Class 2b-5

3.1 Class 4/5 Delivery

Figure III-7 shows the Class 4/5 delivery TCO analysis results. The Class 4/5 delivery analysis includes annual VMT of 35,000 miles/year and a first-owner life of 7 years.

Figure III-7. Class 4/5 Delivery TCO Analysis Results



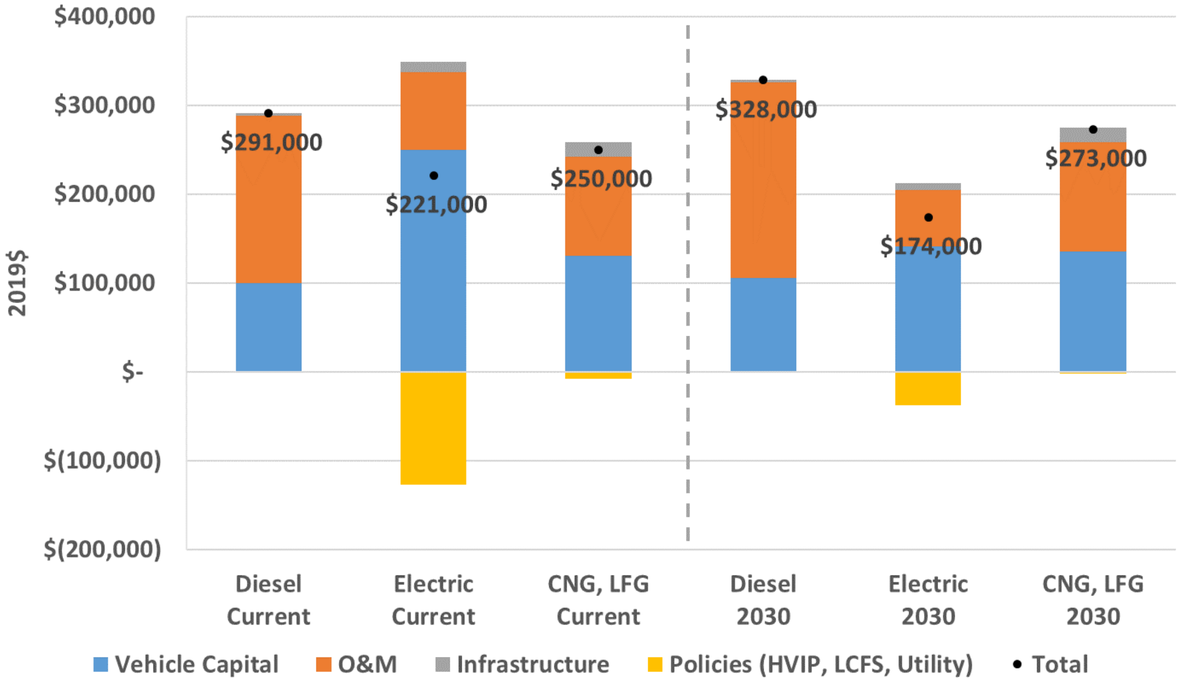
The current fuel cost for the electric truck owner, averaged statewide, was approximately $22,000, with a range of electricity costs between $19,000 and $36,000 depending on the utility.

In the 2030 TCO analysis, the fuel cost, averaged statewide, was approximately $23,000 over the first-owner lifetime, with a range of electricity costs between $22,000 and $36,000 depending on the utility. Maintenance costs decreased from $32,000 to $16,000.

3.2 Class 4/5 Shuttle

Figure III-8 shows the results for the Class 4/5 shuttle TCO analysis. The Class 4/5 shuttle analysis includes VMT of 30,000 miles/year and a first-owner life of 12 years.

Figure III-8. Class 4/5 Shuttle TCO Analysis Results



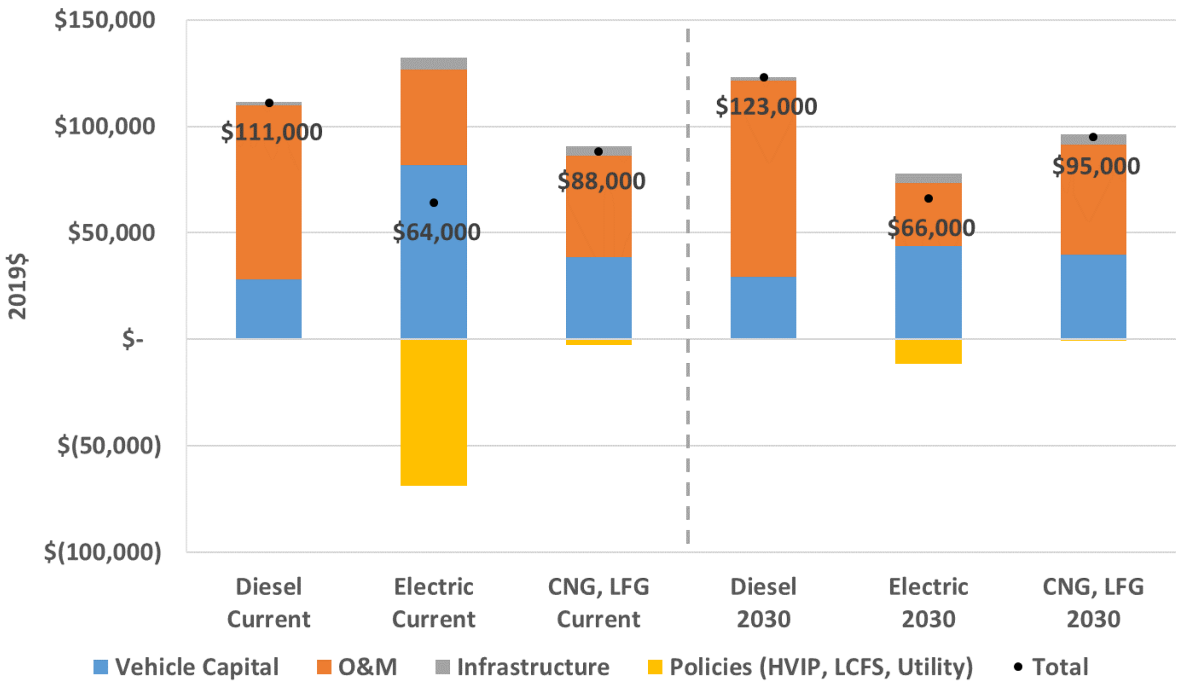
The current fuel cost for the Class 4/5 shuttle, averaged statewide, was approximately $31,000 over the first-owner lifetime, with a range of electricity costs between $36,000 and $58,000 depending on the utility.

In the 2030 TCO analysis the fuel cost, averaged statewide, was approximately $38,000 over the first-owner lifetime, with a range of electricity costs between $35,000 and $58,000 depending on the utility. Maintenance costs decreased from $51,000 to $26,000

3.3 Class 3 – Small Walk-In/Delivery

Figure III-9 shows the results for the Class 3 walk-in TCO analysis. The Class 3 analysis includes annual VMT of 25,000 miles and a first owner life of seven years.

Figure III-9. Class 3 Walk-In TCO Analysis Results



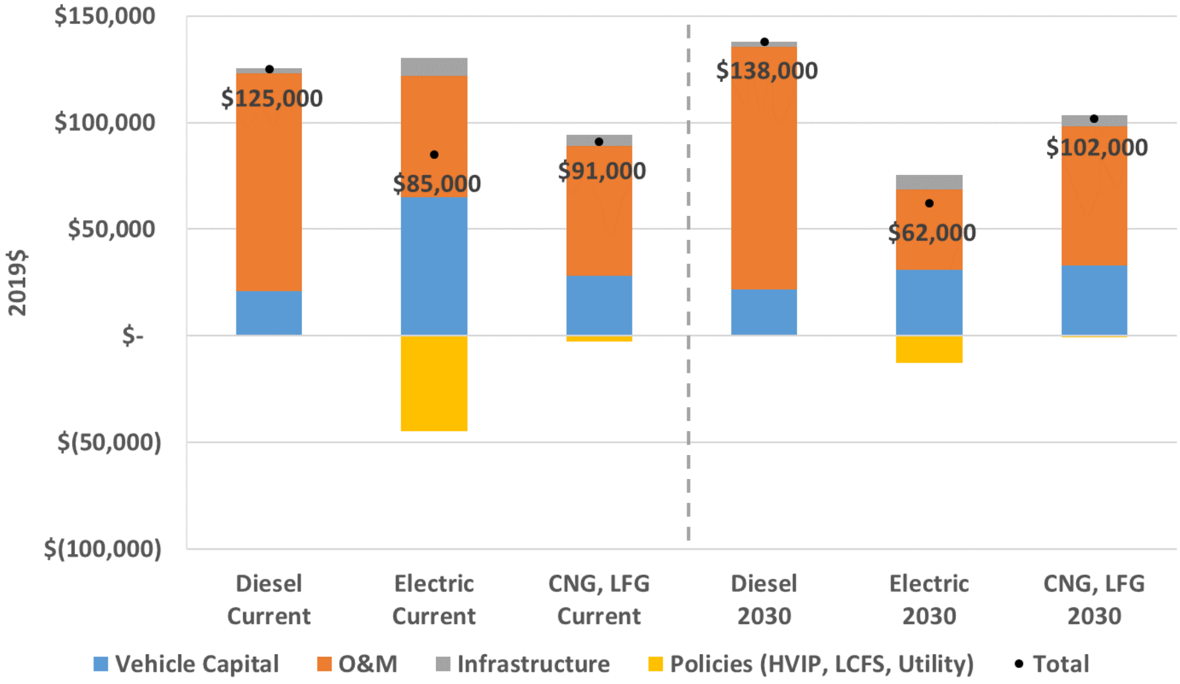
The current fuel cost for the Class 3 walk-in, averaged statewide, was approximately $14,000 over the first-owner lifetime, with a range of $12,000 to$23,000 depending on the utility.

In the 2030 TCO analysis the fuel cost, averaged statewide, was approximately $14,000 over the first-owner lifetime, with a range of electricity costs between $12,000 and $23,000 depending on the utility. Maintenance costs decreased from $31,000 to $15,000.

3.4 Class 2b –Van

Figure III-10 shows the TCO analysis results for the Class 2b van. The Class 2b van analysis includes annual VMT of 25,000 miles and a 10-year vehicle life.

Figure III-10. Class 2b Van TCO Analysis Results



The current fuel cost for the Class 2b Van, averaged statewide, was approximately $16,000 over the first-owner lifetime, with a range of electricity costs between $14,000 and $26,000 depending on the utility.

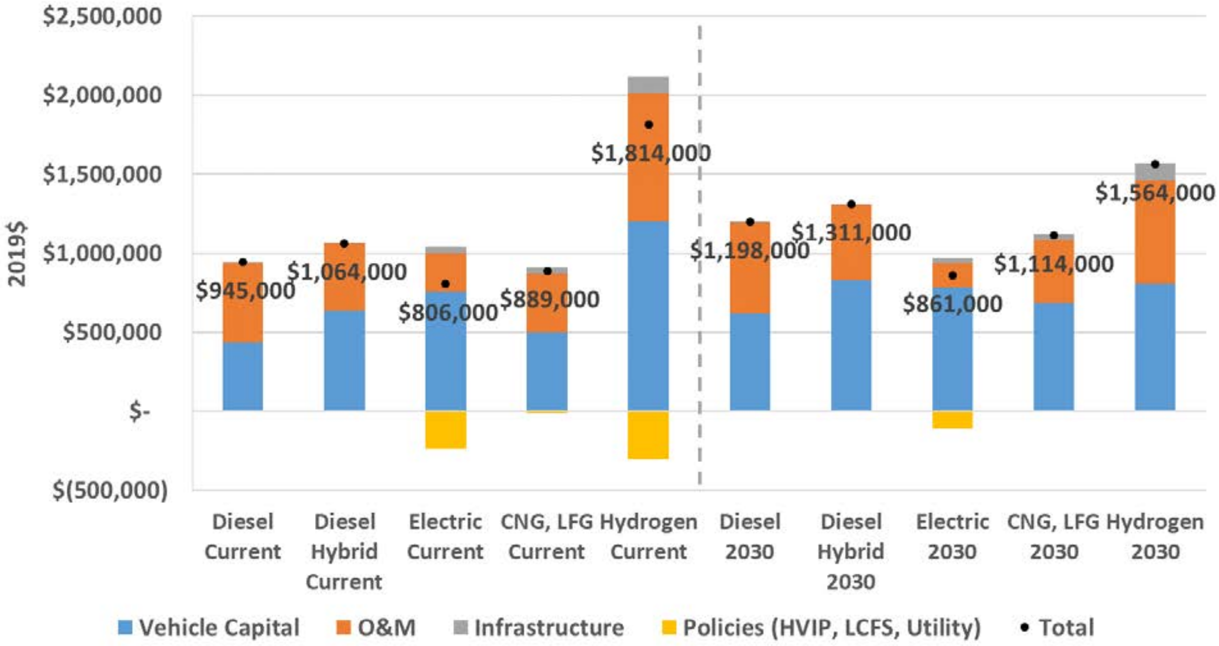
In the 2030 TCO analysis the fuel cost, averaged statewide, was approximately $17,000 over the first-owner lifetime, with a range of$16,000 to$26,000 depending on the utility. Maintenance costs decreased from $31,000 to $15,000.

4. Buses

4.1 40’ Transit Bus

Figure III-11 shows the transit bus TCO analysis results. The transit bus vehicle price projections are based on the ICT analysis and show a different cost trajectory compared to the truck price forecasts in truck TCO results.

Figure III-11. Transit Bus TCO Analysis Results



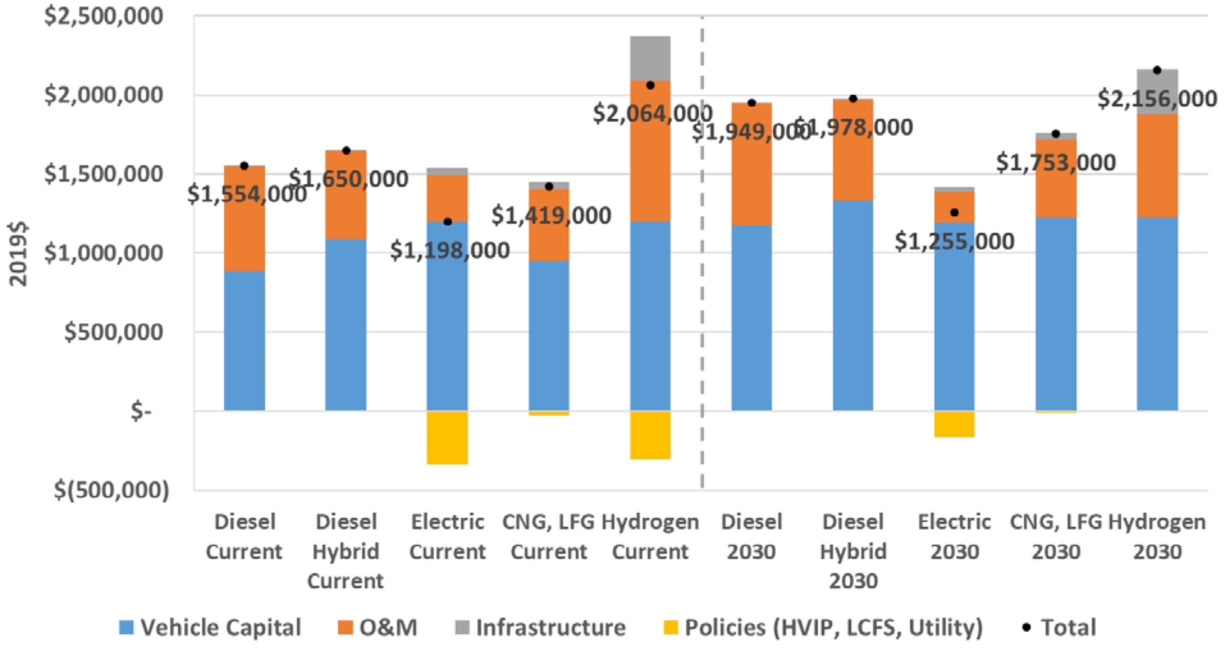
The current fuel cost for the electric bus, averaged statewide, was approximately $64,000 over the first-owner lifetime, with a range of electricity costs between $56,000 and $111,000 depending on the utility.

In the 2030 TCO analysis the fuel cost for the electric bus, averaged statewide, was approximately $62,000 over the first-owner lifetime, with a range of electricity costs between $67,000 and $111,000 depending on the utility. The maintenance costs also decreased from $180,000 to $90,000 based on the assumption that maintenance costs per mile for electric trucks would reduce by 50% from current to 2030. Natural gas buses using LFG consistently had a lower TCO than diesel, diesel hybrid, and hydrogen buses.

4.2 60’ Articulated Bus

Figure III-12 shows the TCO analysis results for articulated buses. This vehicle price trajectories for this analysis are based off the ICT transit bus escalations.

Figure III-12. Articulated Bus TCO Analysis Results



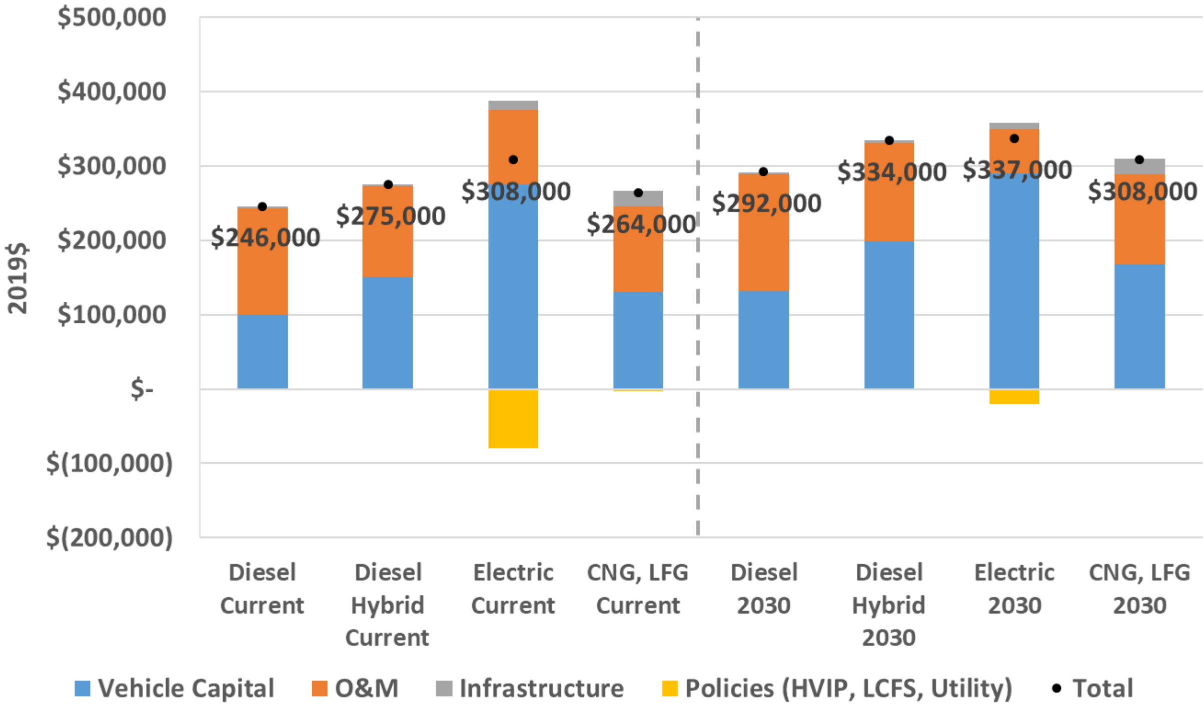
The current fuel cost for the electric bus owner, averaged statewide, was approximately $98,000 over the first owner lifetime, with a range of electricity costs between $81,000 and $191,000 depending on the utility.

In the 2030 TCO analysis the fuel cost for the electric bus owner, averaged statewide, was approximately $100,000 over the first owner lifetime, with a range of electricity costs between $91,000 and $166,000 depending on the utility. Maintenance costs decreased from $197,000 to $98,000.

4.3 Type A School Bus

Figure III-13 shows the Type A school bus TCO analysis results. The school bus analysis assumes annual VMT of 11,200 miles per year and the first owner being the only owner for the full 12-year vehicle life.

Figure III-13. Type A School Bus TCO Analysis Results



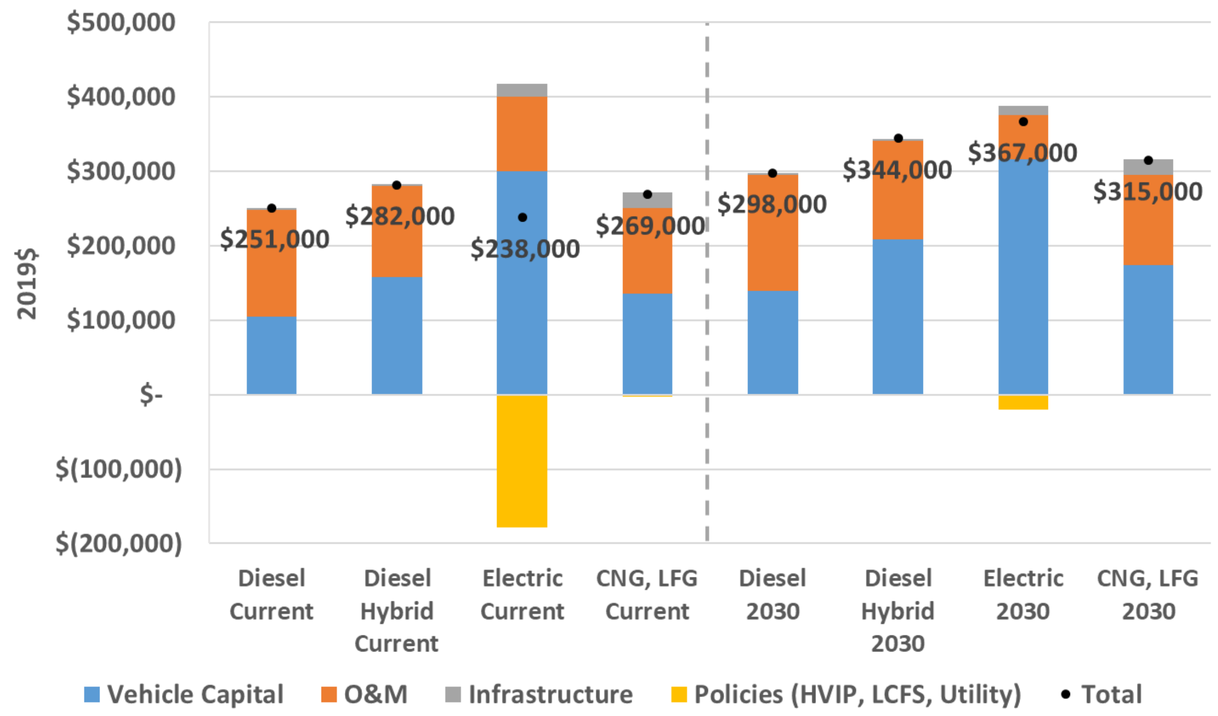
The analysis shows that unlike the results in other categories, for Type A school buses the conventional diesels have the lowest current TCO. Their low annual VMT means electric school buses cannot take full advantage of lower fuel costs relative to diesel and natural gas. The HVIP incentive for electric buses (currently $55,000) is insufficient to make electric school buses have a lower TCO than diesel or natural gas. Electric buses do have lower O&M costs including fuel and vehicle maintenance. The fuel cost for the electric bus owner, averaged statewide, was approximately $14,000 over the first-owner lifetime, with a range of electricity costs between $11,000 and $22,000 depending on the utility.

In the 2030 TCO analysis, the forecasted lower O&M costs allow for electric to be almost cost competitive on a TCO basis even without the HVIP incentive. In 2030 the fuel cost, averaged statewide, was approximately $16,000 over the first-owner lifetime, with a range of electricity costs between $15,000 and $22,000 depending on the utility. Maintenance costs decreased from $86,000 to $43,000.

4.4 Type C School Bus

Figure III-14 shows the Type C school TCO analysis results. The school bus analysis assumes annual VMT of 11,200 miles per year and the first owner being the only owner for the full 12-year vehicle life.

Figure III-14. Type C School Bus TCO Analysis Results



The analysis shows that the electric Type C school buses have the lowest current TCO as a result of the entire incentive package of a $150,000 HVIP voucher, the LCFS, and utility programs. The fuel cost, averaged statewide, was approximately $14,000 over the first-owner lifetime, with a range of electricity costs between $11,000 and $22,000 depending on the utility.

In the 2030 TCO analysis, the forecasted lower O&M costs allow for electric to be almost cost competitive on a TCO basis without the HVIP incentive. Again, the low annual VMT does not allow for the electric school buses to take full advantage of the lower fuel costs. Diesel followed by natural gas have the lowest TCO for the 2030 analysis. In 2030 the fuel cost, averaged over a statewide basis, was approximately $16,000 over the first-owner lifetime, with a range of electricity costs between $15,000 and $22,000 depending on the utility. Maintenance costs decreased from $86,000 to $43,000.

IV. TCO Conclusions

In the near-term, incentives are critical for the TCO of electric trucks and buses to be competitive with diesel and natural gas technologies, but in the 2030 timeframe, electric technologies will be able to compete by themselves on a TCO basis without large vehicle incentives.

Across nearly all of the vehicle types and duty cycles, EVs in 2019 have the lowest current TCO when taking into account incentives such as HVIP, LCFS, and utility programs. The only exceptions are Type A school buses and Class 6 regional haul trucks. The HVIP incentive is the most critical for current electric trucks and buses to be competitive on a TCO basis. Without this incentive for electric technologies, diesel and/or natural gas options for almost all categories have a lower TCO. In addition to the incentives, new rate structures combined with optimized charging around low- or off-peak periods for vehicle charging result in significant fuel cost savings for electric trucks and buses. A potential barrier to overcome will be getting truck fleets, especially smaller truck fleets, acclimated to the transition from refueling to charging to take advantage of these lower rates. An adjustment from existing driving/work patterns will likely be necessary for expansive electrification.

In the 2030 timeframe, electric trucks and buses should be able to compete without HVIP incentives on a TCO basis. The only exceptions are electric school buses, which continue to have a higher TCO than other technologies because their low VMT means they cannot take advantage of lower fuel costs to fully offset their higher incremental costs. Even though electric trucks and buses, for the most part, have the lowest TCO in 2030 without HVIP, the remaining incremental cost of these vehicles over diesel may be an adoption barrier. In most cases, diesel vehicles still have a lower initial purchase price in 2030, but electric trucks and buses are cost competitive or even cheaper than natural gas on upfront costs. In 2030 the lower TCO of electric trucks and buses compared to diesel and natural gas is driven by lower operating costs from optimizing around EV rate structures and the assumed reduction in maintenance costs for electric trucks.

Certain vehicle classes, especially Class 8, will likely see increases in battery size as a response to reductions in battery costs. This will allow additional uses and duty cycles to perform a full day’s operation on a single charge. The result would be higher overall vehicle prices in 2030 than what is projected in the TCO analysis. Increased battery packs would also increase the weight of electric trucks. In 2018, California adopted AB2061, which increased the upper weight limit of a zero- or near-zero emission vehicle by 2,000 lbs. This higher weight limit reduces or potentially eliminates weight concerns for most Class 2b to 7 vehicles and reduces concerns for local or regional Class 8 vehicles.

Looking forward, costs will certainly be influenced by the choices made by manufacturers. Vertically integrated battery and vehicle manufacturers have the potential for lower cost business models compared to OEMs that purchase full battery packs or battery cells. These vertically integrated companies, such as Tesla, have quoted much lower purchase prices for Class 8 trucks. Certain OEMs, especially those that are multi-fueled (diesel, natural gas, and electric), have indicated their intention to focus EVs on specific market segments, while other EV truck companies, such as BYD, will look to produce EVs across all market segments. Manufacturers also warned that there could be potential short-term increases in battery prices for companies that purchase battery cells and packs while supply chains expand to meet the demand of MD/HD EVs.

The future of HVIP is critical to the success of all alternative fuel vehicles, but especially electric trucks and buses. The 2018-2019 HVIP funding level of $125 million only funds a few hundred to a few thousand trucks and buses depending on voucher levels and types of vehicles.[41] The

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[41] CARB, 2018c

successful transition to electric trucks and buses could be contingent on increases in HVIP funding in the near-term when there are higher incremental costs. Multi-year appropriations rather than the current annual appropriations could provide more certainty. Over time, voucher levels could be reduced as incremental costs decrease.

V. Appendix A – Vehicle Price Forecast

1. Memorandum – Vehicle Prices and Forecast

In the following section, the methodology for developing projected truck prices for diesel, natural gas, and battery electric will be discussed with figures at the end of the section showing the results of the price forecast.

For diesel trucks, ICF started with current truck prices from both the California Energy Commission Revised Transportation Energy Demand Forecast 2018-2030[42] and an extensive literature review performed by ICF.[43] ICF utilized truck price projections from the Revised Transportation Energy Demand Forecast for diesel trucks to determine relative price increases from the current prices and to project conventional diesel truck prices from 2019 to 2032.

For natural gas trucks, ICF started with current truck prices from both the California Energy Commission Revised Transportation Energy Demand Forecast 2018-2030[44] and an extensive literature review performed by ICF.[45] Since Cummins-Westport has transitioned completely to low-NOx 8.9L engines, ICF is assuming that all natural gas engines will transition to low-NOx and the pricing will hold for these engines. ICF utilized truck price projections from the Revised Transportation Energy Demand Forecast for natural gas trucks to determine relative price increases from the current prices and to project natural gas truck prices from 2019 to 2032. Table V-1 and Table V-2 show the 2018 conventional diesel and low-NOx natural gas truck prices and the annual prices increases for diesel and natural gas trucks.

Table V-1. 2018 Conventional Truck Prices

Fuel Type	Class 4-5	Class 6-7	Class 8 SH	Class 8 LH
Diesel	$48,000	$63,000	$110,000	$160,000
Low-NOx Natural Gas	$68,000	$95,000	$140,000	$190,000

Table V-2. Annual Price Increases for Diesel and Natural Gas Trucks

	Class 4-7 Diesel	Class 4-7 Natural Gas	Class 8 Diesel	Class 8 Natural Gas
2018-2020	0.91%	0.82%	1.32%	1.06%
2021-2025	0.43%	0.28%	0.61%	0.38%
2025-2032	0.25%	0.17%	0.29%	0.18%

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[42] CEC, 2018
[43] ICF, 2018
[44] CEC, 2018
[45] ICF, 2018

Similar to natural gas and diesel trucks, the battery electric price projections start with current truck prices. The projection methodology differs from conventional trucks by separating the battery and balance of truck prices and applying separate cost reduction curves and factors to each portion of the truck. The starting point for the current 2019 battery electric truck prices are based on extensive literature review by ICF[46] and conversations with current battery electric truck manufacturers. Since many Class 6-8 electric trucks are currently imported from China, the prices supplied by the manufacturers include a 25% tariff on the cost (not price). ICF assumed a 20% profit on trucks to estimate the tariff and isolate the non-tariff price of the truck. There is no tariff amount for Class 4/5 trucks because a significant portion of these trucks are already being made in the United States.[47] Table V-3 includes the tariff and provides non-tariff prices and separate breakdowns for SH and LH within each truck category to account for differences in battery sizes.

Table V-3. Battery Electric Truck 2019 Prices With the Tariff and Estimated Non-Tariff Prices

Truck Type	Battery Size (kWh)	Price (2019$)	Est. Tariff Amount (2019$)	Est Vehicle Price (2019$)
Class 4-5 SH	100	$100,000	–	$100,000
Class 6-7 SH	150	$200,000	$33,300	$166,700
Class 8 SH	250	$300,000	$50,000	$250,000
Class 4-5 LH	150	$150,000	–	$150,000
Class 6-7 LH	250	$300,000	$50,000	$250,000
Class 8 LH	500	$450,000	$75,000	$375,000

The next step in developing price projections for battery electric trucks is separating the balance of truck from the battery. In discussions with vehicle manufacturers, there is a higher balance of truck cost when increasing the battery pack size to take into account either the larger wheelbase or other parts and labor to hold the additional packs. ICF assumed a 20% increase in the balance of truck cost to take into account the larger pack.

ICF used the cost ranges and battery pack sized for the vehicles shown in Table V-3 to estimate a fully loaded battery price of $375/kWh. This cost was mainly based on the Class 8 costing that has the largest battery packs. Table V-4 shows the estimated battery and balance of truck prices using the determined fully loaded battery price.

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[46] Ibid.

[47] The workhorse Class4/5 stepvan developed for UPS has an estimated price of $133,000 and a 130 kWh battery pack, which places the cost squarely in between the SH and LH Class 4/5 prices.

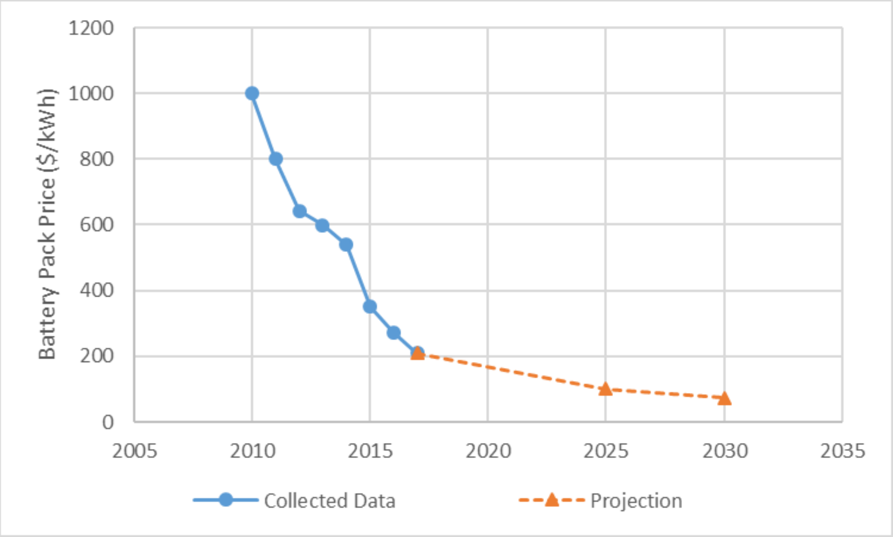
Table V-4. Estimated Battery Pack and Balance of Truck Prices (2019$)

Truck Type	Est Battery Price (2019$)	Est Balance of Truck (2019$)
Class 4-5 SH	$38,000	$62,000
Class 6-7 SH	$56,000	$110,700
Class 8 SH	$94,000	$156,000
Class 4-5 LH	$56,000	$94,000
Class 6-7 LH	$94,000	$156,000
Class 8 LH	$188,000	$187,000

ICF's results are similar to the results of the analysis performed by CARB for regional Class 8 tractors ($425,000 in 2018, $232,000 in 2024 and $196,000 in 2030).[48]

To project future prices, the Bloomberg New Energy Finance (BNEF) price curves from the ICF literature review were applied to the current estimated truck battery pack price of $375/kWh. The forecast estimates a 58% price reduction of battery pack price in $/kWh from 2019 to 2030. ICF used the CEC Revised Transportation Demand Forecast for electric trucks, with an assumed 200 kWh battery pack for Class 6 trucks, to extract their assumed balance of truck cost reductions. The result is an estimated 37% decrease in the price of the balance of truck from 2019 to 2030.Figure V-1 and Figure V-2 show the BNEF battery price curve and the price reduction curves for the balance of truck and batteries used for the price projections.

Figure V-1. BNEF Battery Price Curve



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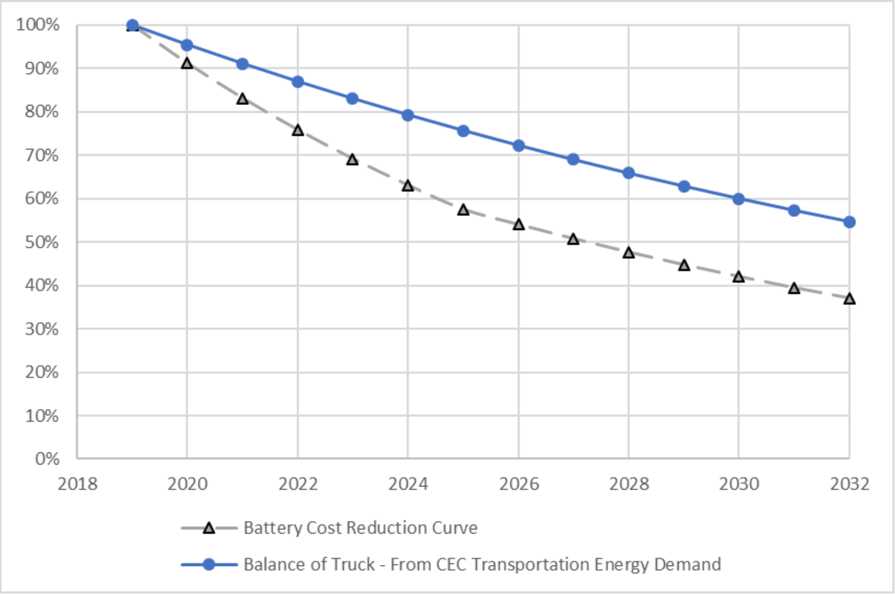
[48] CARB, 2019a

Figure V-2. Balance of Truck and Battery Cost Reduction Curves



The following sets of figures show the price projections for Class 4-5, Class 6-7, and Class 8 for diesel, natural gas, and battery electric trucks. In the Class 4-5 and 6-7 figures, there are two projections for battery electric from the increased battery pack sizes and only one projection for diesel and natural gas. The same Class 4-5 and 6-7 diesel and natural gas trucks can perform both the SH and LH duty cycles. In the Class 8 figure, there are two projections for diesel and natural gas since different vehicle configurations are required for SH and LH in Class 8 resulting in different priced vehicles.

Figure V-3. Class 4-5 Vehicle Price Projections

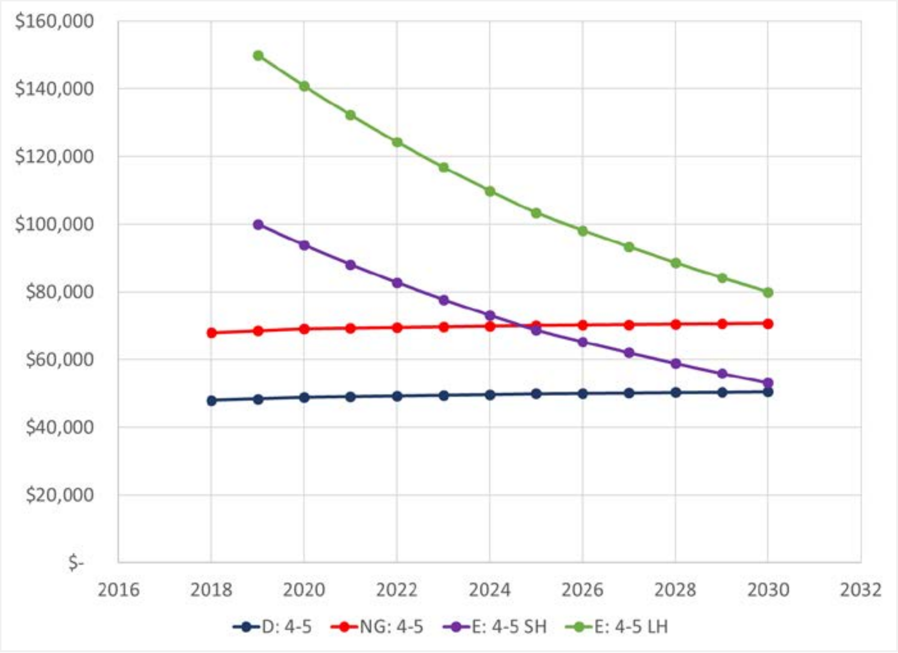


Figure V-4. Class 6-7 Vehicle Price Projections

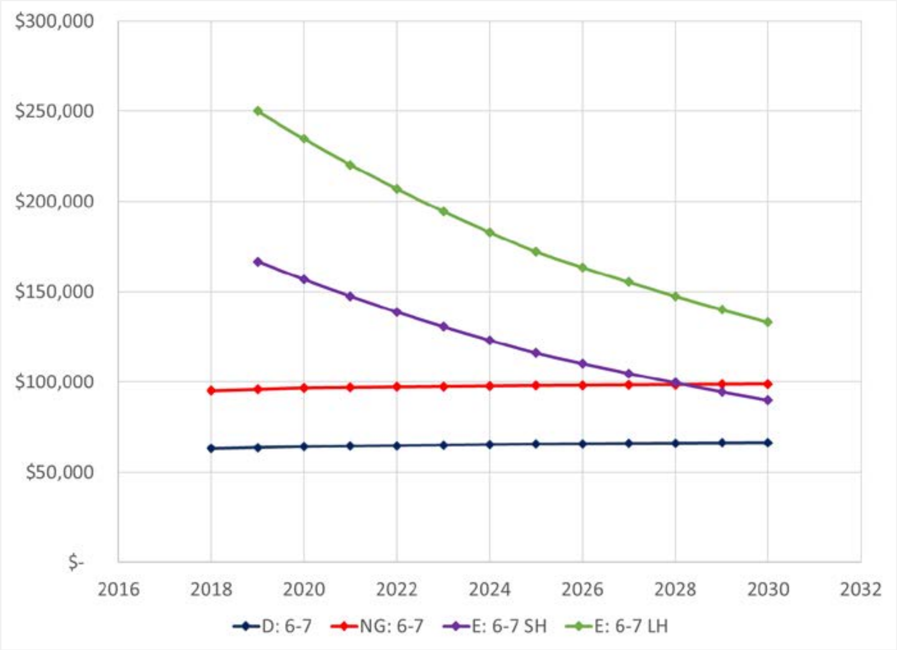
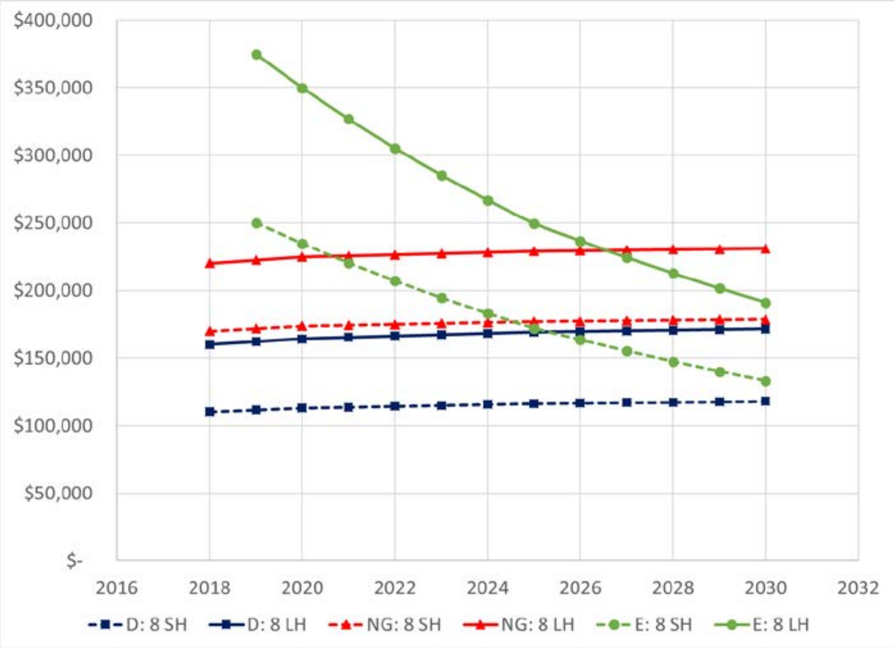


Figure V-5. Class 8 Vehicle Price Projections



Low-NOx Diesel

In addition to conventional diesel, ICF developed vehicle price projections for low-NOx diesel to be used in the scenario and economic analysis sections. Since additional technology, research, and engineering will be required for diesel trucks to meet low-NOx requirements, there will be an incremental cost for low-NOx diesel trucks over conventional diesel trucks. After discussions with the Manufacturers of Emission Controls Association, a conservative incremental cost of $10,000 was assigned to Class 8 trucks. An International Council on Clean Transportation (ICCT) report on diesel emission control technology[49] showed that Class 6 emission controls were approximately 75% of the cost of Class 8 resulting in an incremental cost of $7,500 for low-NOx diesel Class 6 over conventional Class 6 diesel trucks. ICF made the assumption that the incremental cost for Class 4/5 diesel trucks would be 50% of Class 8 diesel trucks. The low-NOx diesel incremental costs were not included in the TCO analysis, but these incremental costs will be included in the vehicle prices for the Scenario Analysis where low-NOx diesel trucks are included in the scenarios. Table V-5 shows the low-NOx incremental costs for Class 4/5, Class 6/7, and Class 8 vehicles.

Table V-5. Low-NOx Diesel Incremental Costs

Class	Low-NOx Diesel Incremental Cost
4/5	$5,000
6/7	$7,500
8	$10,000

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[49] ICCT, 2016

VI. Appendix B – TCO Details by Vehicle Segment

1. TCO Details

The following tables contain the detailed information contained within the figures in Section III with all values in 2019 dollars.

Table VI-1. Class 8 Tractor Detailed Results

	Diesel Current	Electric Current	CNG, LFG Current	Hydrogen Current	Diesel 2030	Electric 2030	CNG, LFG 2030	Hydrogen 2030
Vehicle Capital	$109,854	$293,722	$130,452	$468,083	$117,407	$141,482	$137,318	$145,813
Vehicle Price	$160,000	$375,000	$190,000	$597,610	$171,000	$191,153	$200,000	$197,005
Residual Value	-$50,146	-$81,278	-$59,548	-$129,526	-$53,593	-$49,671	-$62,682	-$51,192
O&M	$302,104	$126,891	$170,240	$534,984	$371,722	$100,308	$201,581	$332,537
Fuel	$232,183	$63,226	$99,215	$471,319	$301,801	$68,475	$130,556	$300,705
Vehicle O&M	$69,921	$63,665	$71,025	$63,665	$69,921	$31,832	$71,025	$31,832
Infrastructure	$2,642	$25,031	$31,948	$128,199	$2,642	$15,797	$31,948	$128,199
Capital	$0	$13,125	$16,008	$62,342	$0	$9,844	$16,008	$62,342
O&M	$2,642	$11,906	$15,940	$65,857	$2,642	$5,953	$15,940	$65,857
Policies (HVIP, LCFS, Utility)	$0	-$250,438	-$62,626	-$305,125	$0	-$83,073	-$4,519	-$3,489
Total	$414,601	$195,207	$270,013	$826,141	$491,770	$174,514	$366,328	$603,061
12L NG			$21,472				$21,632	

Table VI-2. Class 8 SH Detailed Results

	Diesel Current	Electric Current	CNG, LFG Current	Hydrogen Current	Diesel 2030	Electric 2030	CNG, LFG 2030	Hydrogen 2030
Vehicle Capital	$78,730	$217,478	$100,202	$346,579	$84,456	$110,550	$105,212	$113,934
Vehicle Price	$110,000	$250,000	$140,000	$398,406	$118,000	$133,077	$147,000	$137,150
Residual Value	-$31,270	-$32,522	-$39,798	-$51,827	-$33,544	-$22,527	-$41,788	-$23,216
O&M	$221,503	$93,330	$125,891	$370,816	$269,500	$71,992	$147,758	$228,697
Fuel	$166,533	$43,278	$70,052	$320,763	$214,529	$46,966	$91,919	$203,671
Vehicle O&M	$54,971	$50,052	$55,839	$50,052	$54,971	$25,026	$55,839	$25,026
Infrastructure	$2,538	$26,973	$22,883	$175,297	$2,538	$17,336	$17,017	$175,297
Capital	$0	$15,400	$11,731	$87,278	$0	$11,550	$5,866	$87,278
O&M	$2,538	$11,573	$11,152	$88,019	$2,538	$5,786	$11,152	$88,019
Policies (HVIP, LCFS, Utility)	$0	-$222,306	-$57,225	-$303,478	$0	-$58,119	-$3,161	-$2,441
Total	$302,771	$115,475	$191,751	$589,214	$356,493	$141,759	$266,826	$515,488
12L NG			$21,472				$22,550	

Table VI-3. Class 8 Drayage Detailed Results

	Diesel Current	Electric Current	CNG, LFG Current	Hydrogen Current	Diesel 2030	Electric 2030	CNG, LFG 2030	Hydrogen 2030
Vehicle Capital	$78,730	$217,478	$111,716	$349,471	$84,456	$110,550	$117,302	$113,934
Vehicle Price	$110,000	$250,000	$140,000	$398,406	$118,000	$133,077	$147,000	$137,150
Residual Value	-$31,270	-$32,522	-$28,284	-$48,935	-$33,544	-$22,527	-$29,698	-$23,216
O&M	$217,434	$95,828	$126,431	$364,046	$262,823	$84,656	$141,668	$225,074
Fuel	$165,617	$50,781	$69,667	$318,999	$213,349	$62,133	$91,414	$202,551
Vehicle O&M	$51,817	$45,047	$56,764	$45,047	$49,473	$22,523	$50,255	$22,523
Infrastructure	$2,532	$32,841	$22,757	$175,297	$2,532	$21,738	$16,924	$175,297
Capital	$0	$18,375	$11,667	$87,278	$0	$13,781	$5,833	$87,278
O&M	$2,532	$14,466	$11,091	$88,019	$2,532	$7,956	$11,091	$88,019
Policies (HVIP, LCFS, Utility)	$0	-$223,438	-$57,157	-$303,459	$0	-$57,800	-$3,144	-$2,427
Total	$298,695	$122,709	$203,747	$585,356	$349,810	$159,144	$272,750	$511,878
12L NG			$21,472				$22,550	

Table VI-4. Refuse Detailed Results

	Diesel Current	Electric Current	CNG, LFG Current	Diesel 2030	Electric 2030	CNG, LFG 2030
Vehicle Capital	$150,000	$352,500	$180,000	$160,966	$191,516	$199,000
Vehicle Price	$150,000	$352,500	$180,000	$160,966	$191,516	$199,000
Residual Value	$0	$0	$0	$0	$0	$0
O&M	$543,365	$378,631	$424,200	$599,993	$219,599	$446,674
Fuel	$210,372	$52,552	$89,479	$267,000	$56,560	$111,954
Vehicle O&M	$332,992	$326,079	$334,721	$332,992	$163,040	$334,721
Infrastructure	$3,525	$44,127	$29,142	$3,525	$32,488	$29,142
Capital	$0	$26,400	$15,758	$0	$23,625	$15,758
O&M	$3,525	$17,727	$13,384	$3,525	$8,863	$13,384
Policies (HVIP, LCFS, Utility)	$0	-$246,643	-$14,382	$0	-$69,754	-$3,794
Total	$696,890	$528,614	$618,960	$764,484	$373,849	$671,022
12L NG			$30,000			$31,506

Table VI-5. Class 6 Regional Haul Detailed Results

	Diesel Current	Electric Current	CNG, LFG Current	Diesel 2030	Electric 2030	CNG, LFG 2030
Vehicle Capital	$45,091	$217,478	$67,994	$47,238	$109,341	$70,141
Vehicle Price	$63,000	$250,000	$95,000	$66,000	$133,077	$98,000
Residual Value	-$17,909	-$32,522	-$27,006	-$18,762	-$23,735	-$27,859
O&M	$125,320	$56,955	$75,616	$150,348	$40,720	$87,019
Fuel	$86,840	$21,918	$36,530	$111,869	$23,202	$47,932
Vehicle O&M	$38,479	$35,036	$39,087	$38,479	$17,518	$39,087
Infrastructure	$2,015	$26,973	$11,933	$2,015	$17,336	$11,933
Capital	$0	$15,400	$6,117	$0	$11,550	$6,117
O&M	$2,015	$11,573	$5,815	$2,015	$5,786	$5,815
Policies (HVIP, LCFS, Utility)	$0	-$131,390	-$51,375	$0	-$30,307	-$1,648
Total	$172,426	$170,017	$104,169	$199,601	$137,091	$167,445

Table VI-6. Class 6 Urban Delivery Detailed Results

	Diesel Current	Electric Current	CNG, LFG Current	Diesel 2030	Electric 2030	CNG, LFG 2030
Vehicle Capital	$45,091	$147,292	$67,994	$47,238	$66,183	$70,141
Vehicle Price	$63,000	$166,667	$95,000	$66,000	$89,918	$98,000
Residual Value	-$17,909	-$19,375	-$27,006	-$18,762	-$23,735	-$27,859
O&M	$108,263	$49,899	$67,861	$129,959	$36,241	$75,055
Fuel	$75,280	$19,868	$31,667	$96,977	$21,225	$41,552
Vehicle O&M	$32,982	$30,031	$36,194	$32,982	$15,016	$33,503
Infrastructure	$1,940	$7,215	$10,344	$1,940	$4,832	$10,344
Capital	$0	$4,900	$5,303	$0	$3,675	$5,303
O&M	$1,940	$2,315	$5,041	$1,940	$1,157	$5,041
Policies (HVIP, LCFS, Utility)	$0	-$126,205	-$50,526	$0	-$30,307	-$1,648
Total	$155,293	$78,201	$95,673	$179,137	$76,949	$153,892

Table VI-7. Class 4/5 Delivery Detailed Results

	Diesel Current	Electric Current	CNG, LFG Current	Diesel 2030	Electric 2030	CNG, LFG 2030
Vehicle Capital	$34,355	$122,450	$48,669	$36,502	$65,778	$50,817
Vehicle Price	$48,000	$150,000	$68,000	$51,000	$79,918	$71,000
Residual Value	-$13,645	-$27,550	-$19,331	-$14,498	-$14,140	-$20,183
O&M	$110,943	$54,637	$74,655	$131,011	$39,715	$83,797
Fuel	$69,629	$21,828	$29,289	$89,696	$23,311	$38,432
Vehicle O&M	$41,315	$32,809	$45,365	$41,315	$16,404	$45,365
Infrastructure	$1,903	$7,215	$9,568	$1,903	$4,832	$9,568
Capital	$0	$4,900	$4,905	$0	$3,675	$4,905
O&M	$1,903	$2,315	$4,663	$1,903	$1,157	$4,663
Policies (HVIP, LCFS, Utility)	$0	-$112,698	-$5,111	$0	-$23,296	-$1,322
Total	$147,201	$71,603	$127,780	$169,416	$87,029	$142,860

Table VI-8. Class 4/5 Shuttle/Vans Detailed Results

	Diesel Current	Electric Current	CNG, LFG Current	Diesel 2030	Electric 2030	CNG, LFG 2030
Vehicle Capital	$100,000	$250,000	$130,000	$105,000	$141,000	$135,000
Vehicle Price	$100,000	$250,000	$130,000	$105,000	$141,000	$135,000
Residual Value	$0	$0	$0	$0	$0	$0
O&M	$188,075	$86,833	$111,534	$220,378	$63,213	$123,424
Fuel	$120,005	$35,515	$51,043	$152,308	$37,554	$63,863
Vehicle O&M	$68,070	$51,318	$60,492	$68,070	$25,659	$59,561
Infrastructure	$2,963	$11,945	$16,624	$2,963	$8,073	$16,624
Capital	$0	$8,400	$8,989	$0	$6,300	$8,989
O&M	$2,963	$3,545	$7,635	$2,963	$1,773	$7,635
Policies (HVIP, LCFS, Utility)	$0	-$127,427	-$8,204	$0	-$38,146	-$2,164
Total	$291,037	$221,352	$249,954	$328,340	$174,140	$272,883

Table VI-9. Class 3 Walk-in/Delivery Detailed Results

	Diesel Current	Electric Current	CNG, LFG Current	Diesel 2030	Electric 2030	CNG, LFG 2030
Vehicle Capital	$27,913	$81,690	$38,649	$29,130	$43,563	$39,866
Vehicle Price	$39,000	$100,000	$54,000	$40,700	$53,159	$55,700
Residual Value	-$11,087	-$18,310	-$15,351	-$11,570	-$9,595	-$15,834
O&M	$81,793	$44,836	$47,350	$92,400	$29,686	$51,699
Fuel	$36,804	$13,879	$13,933	$47,411	$14,208	$18,283
Vehicle O&M	$44,989	$30,957	$33,416	$44,989	$15,479	$33,416
Infrastructure	$1,688	$5,822	$4,551	$1,688	$4,661	$4,551
Capital	$0	$4,375	$2,333	$0	$3,938	$2,333
O&M	$1,688	$1,447	$2,218	$1,688	$723	$2,218
Policies (HVIP, LCFS, Utility)	$0	-$68,812	-$2,611	$0	-$11,533	-$785
Total	$111,394	$63,535	$87,940	$123,218	$66,378	$95,331

Table VI-10. Class 2b Van Detailed Results

	Diesel Current	Electric Current	CNG, LFG Current	Diesel 2030	Electric 2030	CNG, LFG 2030
Vehicle Capital	$20,747	$64,815	$28,291	$21,652	$31,121	$32,969
Vehicle Price	$27,500	$75,000	$37,500	$28,700	$39,869	$43,700
Residual Value	-$6,753	-$10,185	-$9,209	-$7,048	-$8,748	-$10,731
O&M	$102,335	$57,201	$60,595	$113,952	$37,503	$65,108
Fuel	$42,299	$15,890	$16,002	$53,916	$16,847	$20,515
Vehicle O&M	$60,036	$41,311	$44,593	$60,036	$20,656	$44,593
Infrastructure	$2,199	$8,180	$5,244	$2,199	$6,590	$5,244
Capital	$0	$6,250	$2,778	$0	$5,625	$2,778
O&M	$2,199	$1,930	$2,467	$2,199	$965	$2,467
Policies (HVIP, LCFS, Utility)	$0	-$44,855	-$2,867	$0	-$12,825	-$873
Total	$125,281	$85,342	$91,264	$137,803	$62,389	$102,449

Table VI-11. Transit Bus Detailed Results

	Diesel Current	Diesel Hybrid Current	Electric Current	CNG, LFG Current	Hydrogen Current	Diesel 2030	Diesel Hybrid 2030	Electric 2030	CNG, LFG 2030	Hydrogen 2030
Vehicle Capital	$435,000	$640,000	$753,000	$500,000	$1,200,000	$615,000	$830,001	$784,000	$685,000	$808,000
Vehicle Price	$435,000	$640,000	$753,000	$500,000	$1,200,000	$615,000	$830,000	$784,000	$685,000	$808,000
Residual Value	$0	$0	$0	$0	$0	$0	$1	$0	$0	$0
O&M	$506,459	$419,632	$244,815	$370,305	$808,482	$578,705	$477,429	$157,024	$398,978	$650,832
Fuel	$268,392	$214,714	$64,004	$114,157	$458,915	$340,638	$272,511	$66,619	$142,830	$301,266
Vehicle O&M	$238,067	$204,918	$180,810	$256,148	$349,567	$238,067	$204,918	$90,405	$256,148	$349,567
Infrastructure	$3,886	$3,886	$44,127	$35,076	$108,706	$3,886	$3,886	$28,663	$35,076	$108,706
Capital	$0	$0	$26,400	$18,000	$75,000	$0	$0	$19,800	$18,000	$75,000
O&M	$3,886	$3,886	$17,727	$17,076	$33,706	$3,886	$3,886	$8,863	$17,076	$33,706
Policies (HVIP, LCFS, Utility)	$0	$0	-$235,486	-$16,329	-$303,304	$0	$0	-$108,306	-$4,841	-$3,737
Total	$945,346	$1,063,518	$806,455	$889,052	$1,813,883	$1,197,591	$1,311,316	$861,381	$1,114,213	$1,563,801

Table VI-12. Articulated Bus Detailed Results

	Diesel Current	Diesel Hybrid Current	Electric Current	CNG, LFG Current	Hydrogen Current	Diesel 2030	Diesel Hybrid 2030	Electric 2030	CNG, LFG 2030	Hydrogen 2030
Vehicle Capital	$887,000	$1,087,000	$1,200,000	$952,000	$1,200,000	$1,172,540	$1,328,353	$1,190,640	$1,223,167	$1,227,088
Vehicle Price	$887,000	$1,087,000	$1,200,000	$952,000	$1,200,000	$1,172,540	$1,328,352	$1,190,640	$1,223,167	$1,227,088
Residual Value	$0	$0	$0	$0	$0	$0	$1	$0	$0	$0
O&M	$662,645	$557,840	$294,331	$450,461	$886,734	$771,254	$644,728	$198,566	$493,566	$649,734
Fuel	$403,483	$322,786	$97,499	$171,616	$689,902	$512,093	$409,674	$100,150	$214,721	$452,903
Vehicle O&M	$259,161	$235,053	$196,832	$278,845	$196,832	$259,161	$235,053	$98,416	$278,845	$196,832
Infrastructure	$4,727	$4,727	$44,127	$43,671	$284,443	$4,727	$4,727	$28,663	$43,671	$284,443
Capital	$0	$0	$26,400	$18,000	$149,620	$0	$0	$19,800	$18,000	$149,620
O&M	$4,727	$4,727	$17,727	$25,671	$134,822	$4,727	$4,727	$8,863	$25,671	$134,822
Policies (HVIP, LCFS, Utility)	$0	$0	-$340,161	-$27,584	-$307,451	$0	$0	-$162,820	-$7,277	-$5,618
Total	$1,554,372	$1,649,567	$1,198,296	$1,418,547	$2,063,725	$1,948,521	$1,977,808	$1,255,049	$1,753,126	$2,155,647

Table VI-13. Type A School Bus Detailed Results

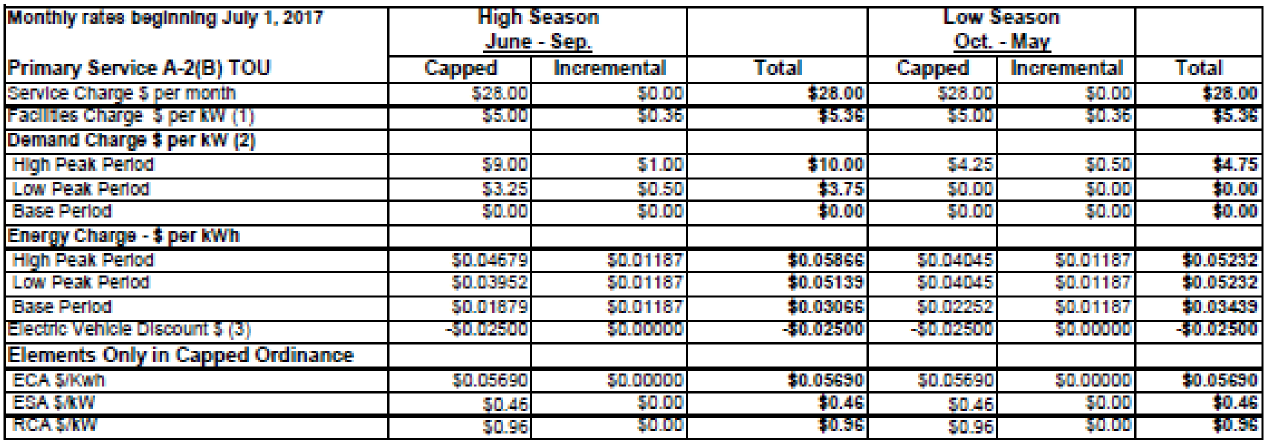
	Diesel Current	Diesel Hybrid Current	Electric Current	CNG, LFG Current	Diesel 2030	Diesel Hybrid 2030	Electric 2030	CNG, LFG 2030
Vehicle Capital	$100,000	$150,000	$275,000	$130,000	$132,192	$198,289	$290,000	$167,029
Vehicle Price	$100,000	$150,000	$275,000	$130,000	$132,192	$198,288	$290,000	$167,029
Residual Value	$0	$0	$0	$0	$0	$1	$0	$0
O&M	$143,225	$122,224	$100,575	$115,746	$156,794	$133,079	$59,676	$121,131
Fuel	$50,409	$40,327	$14,211	$21,441	$63,978	$51,183	$16,494	$26,826
Vehicle O&M	$92,816	$81,896	$86,364	$94,305	$92,816	$81,896	$43,182	$94,305
Infrastructure	$2,530	$2,530	$11,945	$21,207	$2,530	$2,530	$8,073	$21,207
Capital	$0	$0	$8,400	$18,000	$0	$0	$6,300	$18,000
O&M	$2,530	$2,530	$3,545	$3,207	$2,530	$2,530	$1,773	$3,207
Policies (HVIP, LCFS, Utility)	$0	$0	-$79,886	-$3,446	$0	$0	-$20,342	-$909
Total	$245,755	$274,753	$307,634	$263,507	$291,516	$333,898	$337,407	$308,458

Table VI-14. Type C School Bus Detailed Results

	Diesel Current	Diesel Hybrid Current	Electric Current	CNG, LFG Current	Diesel 2030	Diesel Hybrid 2030	Electric 2030	CNG, LFG 2030
Vehicle Capital	$105,000	$157,500	$300,000	$135,000	$138,801	$208,203	$316,000	$173,453
Vehicle Price	$105,000	$157,500	$300,000	$135,000	$138,801	$208,202	$316,000	$173,453
Residual Value	$0	$0	$0	$0	$0	$1	$0	$0
O&M	$143,225	$122,224	$100,575	$115,746	$156,794	$133,079	$59,676	$121,131
Fuel	$50,409	$40,327	$14,211	$21,441	$63,978	$51,183	$16,494	$26,826
Vehicle O&M	$92,816	$81,896	$86,364	$94,305	$92,816	$81,896	$43,182	$94,305
Infrastructure	$2,530	$2,530	$16,745	$21,207	$2,530	$2,530	$11,673	$21,207
Capital	$0	$0	$13,200	$18,000	$0	$0	$9,900	$18,000
O&M	$2,530	$2,530	$3,545	$3,207	$2,530	$2,530	$1,773	$3,207
Policies (HVIP, LCFS, Utility)	$0	$0	-$178,886	-$3,446	$0	$0	-$20,342	-$909
Total	$250,755	$282,253	$238,434	$268,507	$298,125	$343,811	$367,007	$314,882

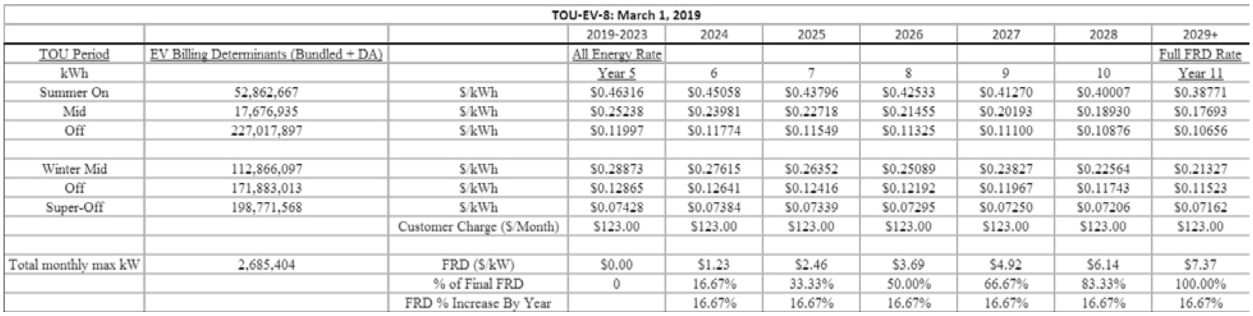
2. Electricity Rate Structures

LADWP TOU - A-2(B)[50]



Monthly rates beginning July 1, 2017	High Season June - Sep.			Low Season Oct. - May		
Primary Service A-2(B) TOU	**Capped**	**Incremental**	**Total**	**Capped**	**Incremental**	**Total**
Service Charge $ per month	$28.00	$0.00	**$28.00**	$28.00	$0.00	**$28.00**
Facilities Charge $ per kW (1)	$5.00	$0.36	**$5.36**	$5.00	$0.36	**$5.36**
Demand Charge $ per kW (2)						
High Peak Period	$9.00	$1.00	**$10.00**	$4.25	$0.50	**$4.75**
Low Peak Period	$3.25	$0.50	**$3.75**	$0.00	$0.00	**$0.00**
Base Period	$0.00	$0.00	**$0.00**	$0.00	$0.00	**$0.00**
Energy Charge - $ per kWh						
High Peak Period	$0.04679	$0.01187	**$0.05866**	$0.04045	$0.01187	**$0.05232**
Low Peak Period	$0.03952	$0.01187	**$0.05139**	$0.04045	$0.01187	**$0.05232**
Base Period	$0.01879	$0.01187	**$0.03066**	$0.02252	$0.01187	**$0.03439**
Electric Vehicle Discount $ (3)	-$0.02500	$0.00000	**-$0.02500**	-$0.02500	$0.00000	**-$0.02500**
Elements Only in Capped Ordinance						
ECA $/Kwh	$0.05690	$0.00000	**$0.05690**	$0.05690	$0.00000	**$0.05690**
ESA $/kW	$0.46	$0.00	**$0.46**	$0.46	$0.00	**$0.46**
RCA $/kW	$0.96	$0.00	**$0.96**	$0.96	$0.00	**$0.96**

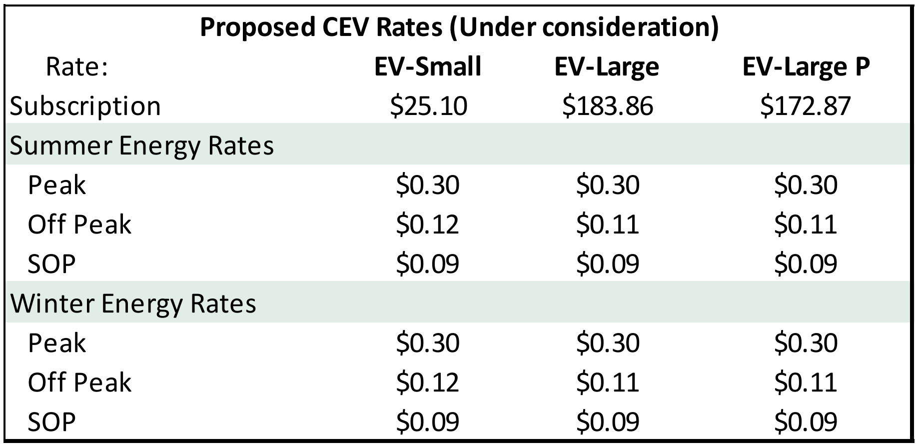
SCE TOU-EV8[51,52]



TOU-EV-8: March 1, 2019

			2019-2023	2024	2025	2026	2027	2028	2029+
TOU Period	EV Billing Determinants (Bundled + DA)		All Energy Rate						Full FRD Rate
kWh			Year 5	6	7	8	9	10	Year 11
Summer On	52,862,667	$/kWh	$0.46316	$0.45058	$0.43796	$0.42533	$0.41270	$0.40007	$0.38771
Mid	17,676,935	$/kWh	$0.25238	$0.23981	$0.22718	$0.21455	$0.20193	$0.18930	$0.17693
Off	227,017,897	$/kWh	$0.11997	$0.11774	$0.11549	$0.11325	$0.11100	$0.10876	$0.10656
Winter Mid	112,866,097	$/kWh	$0.28873	$0.27615	$0.26352	$0.25089	$0.23827	$0.22564	$0.21327
Off	171,883,013	$/kWh	$0.12865	$0.12641	$0.12416	$0.12192	$0.11967	$0.11743	$0.11523
Super-Off	198,771,568	$/kWh	$0.07428	$0.07384	$0.07339	$0.07295	$0.07250	$0.07206	$0.07162
		Customer Charge ($/Month)	$123.00	$123.00	$123.00	$123.00	$123.00	$123.00	$123.00
Total monthly max kW	2,685,404	FRD ($/kW)	$0.00	$1.23	$2.46	$3.69	$4.92	$6.14	$7.37
		% of Final FRD	0	16.67%	33.33%	50.00%	66.67%	83.33%	100.00%
		FRD % Increase By Year		16.67%	16.67%	16.67%	16.67%	16.67%	16.67%

PG&E EV Large[53]



Proposed CEV Rates (Under consideration)

Rate:	EV-Small	EV-Large	EV-Large P
Subscription	$25.10	$183.86	$172.87
Summer Energy Rates			
Peak	$0.30	$0.30	$0.30
Off Peak	$0.12	$0.11	$0.11
SOP	$0.09	$0.09	$0.09
Winter Energy Rates			
Peak	$0.30	$0.30	$0.30
Off Peak	$0.12	$0.11	$0.11
SOP	$0.09	$0.09	$0.09

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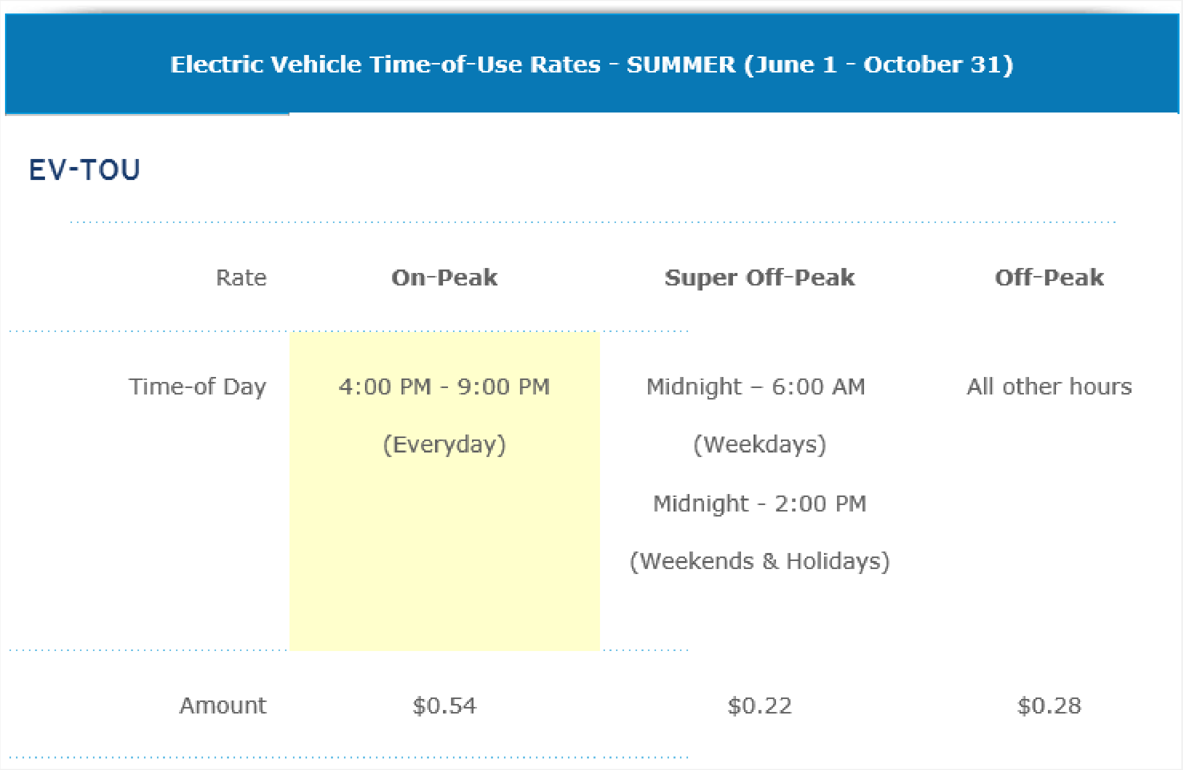
[50] LADWP, 2017

[51] SCE, 2019

[52] The rates shown above are based on the point in time of March 1, 2019, and do not reflect future revenue requirement or revenue allocation changes that impact rate levels. The table should be viewed from the perspective of portraying the rate structure to capture the effect of waiving demand charges, then re-introducing them in a graduated manner. Revenue requirements or allocation in the future and resulting rates are likely to differ from this snapshot in time.

[53] PG&E, 2019

SDG&E TOU EV[54]



Electric Vehicle Time-of-Use Rates - SUMMER (June 1 - October 31)

EV-TOU

Rate	**On-Peak**	**Super Off-Peak**	**Off-Peak**
Time-of Day	4:00 PM - 9:00 PM (Everyday)	Midnight – 6:00 AM (Weekdays) Midnight - 2:00 PM (Weekends & Holidays)	All other hours
Amount	$0.54	$0.22	$0.28

Electric Vehicle Time-of-Use Rates - WINTER (November 1 - May 31)

EV-TOU

Rate	**On-Peak**	**Super Off-Peak**	**Off-Peak**
Time-of Day	4:00 PM - 9:00 PM (Everyday)	Midnight – 6:00 AM (Weekdays) Midnight - 2:00 PM (Weekends & Holidays)	All other hours
Amount	$0.24	$0.22	$0.23

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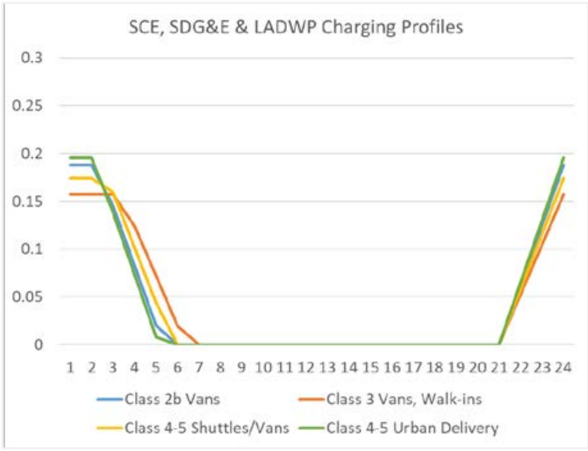
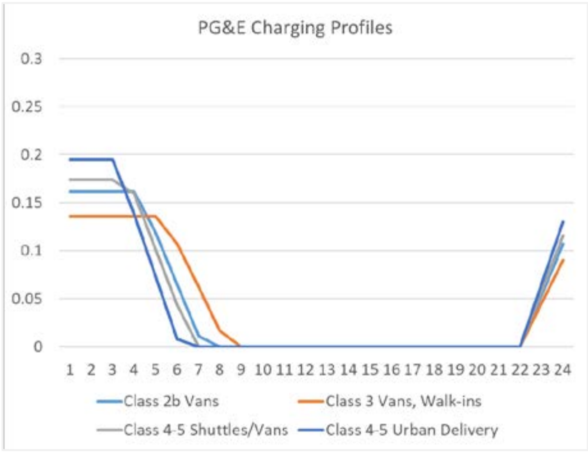
[54] SDG&E, 2017

3. Load Profiles

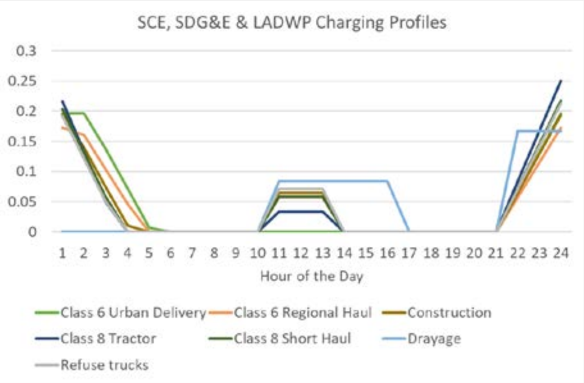
The following load profiles were developed and utilized in the analysis to determine effective annual electricity rates.

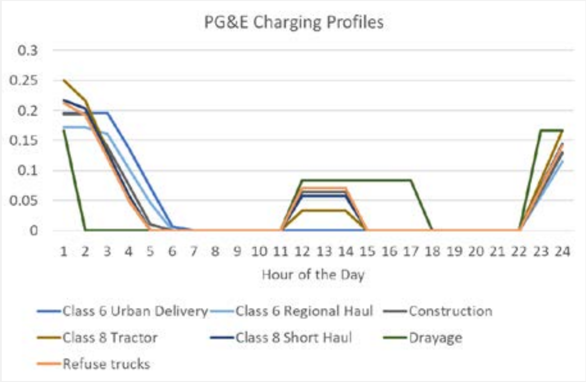
Class 2b – 4 Load Profiles



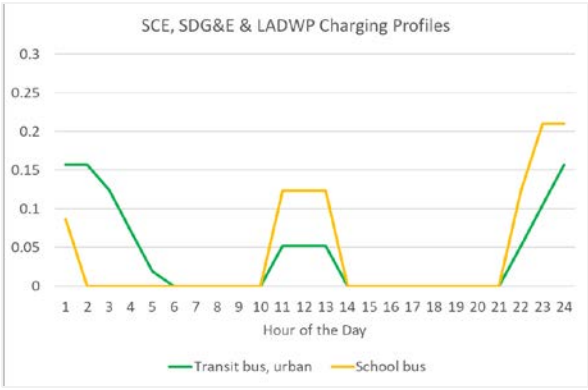


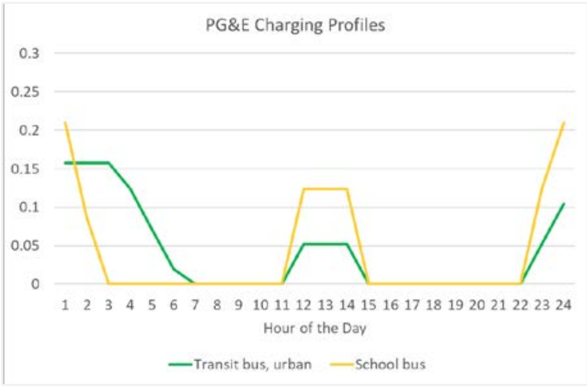
Class 6 – 8 Load Profiles





Transit and School Bus Load Profiles





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Comparison of Medium- and Heavy-Duty Technologies in California

Part 3

Economic Analysis

December 2019

Submitted by:
ICF
75 East Santa Clara St.
Suite 600
San Jose, CA 95113

Prepared for:

California Electric Transportation Coalition
Natural Resources Defense Council

In Partnership With:
Union of Concerned Scientists
Earthjustice
BYD
Ceres
NextGen Climate America

With Advisory Support From:
University of California, Davis Policy Institute for Energy, Environment and the Economy
East Yard Communities for Environmental Justice

ICF

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Abbreviations and Acronyms

BEA	U.S. Bureau of Economic Analysis
BEV	Battery Electric Vehicle
DOF	State of California Department of Finance
FTE	full-time equivalent
GRP	gross regional product
GSP	Gross State Product
HD	heavy-duty
L	liter
LPC	local purchase coefficient
MD	medium-duty
MD/HD	medium- and heavy-duty
NAICS	North American Industry Classification System
NGV	natural gas vehicle
RNG	renewable natural gas

I. Purpose

The economic analysis projected the net economic impact of the previously-defined scenarios (Current Policies, Diesel, Natural Gas, Electricity, and Electricity Max), taking into account direct, indirect and induced effects and the impact of contraction in the gasoline and diesel sectors. The economic modeling considered spending on vehicles, infrastructure and fuel, and reinvestment of a portion of fuel savings into increased production by the industry sectors most involved in MD and HD trucking. This portion of the report is divided into the following sections:

- Methodology
- Results
- Conclusions

II. Methodology

Regional economic modeling is founded on the principle that industry sectors are interdependent--one industry purchases inputs from other industries and households and then sells outputs to other industries, households, and government entities. Therefore, economic activity in one sector causes an increased flow of money throughout the economy. This analysis uses the modeling software IMPLAN[1] (version 3.1) to calculate these impacts. IMPLAN is widely used by municipalities and other entities throughout North America, so the results of this analysis are comparable to other regional economic assessments.

The impact of each scenario is driven by four key spending/reinvestment categories: vehicle expenditures, fueling infrastructure development, fuel spending, and reinvestment of fuel savings. This spending and reinvestment directly impacts the affected industries. In addition, the spending under each scenario generates secondary economic activity in other industries across the state. The full economic impact of each scenario can be assessed through economic impact modeling.

The results of this analysis are reported using four commonly used metrics, consistent with best practices across economic impact analyses:

- **Employment**: The job-years created in each industry, based on the output per worker for each industry.
- **Labor income**: All forms of employment income generated by the direct input, including employee compensation (wages and benefits) and proprietor income.
- **Gross regional product**: The net value of output, including labor income, indirect business taxes, and business income.
- **Industry activity**: Represents the total value of industry activity generated by the direct spending.

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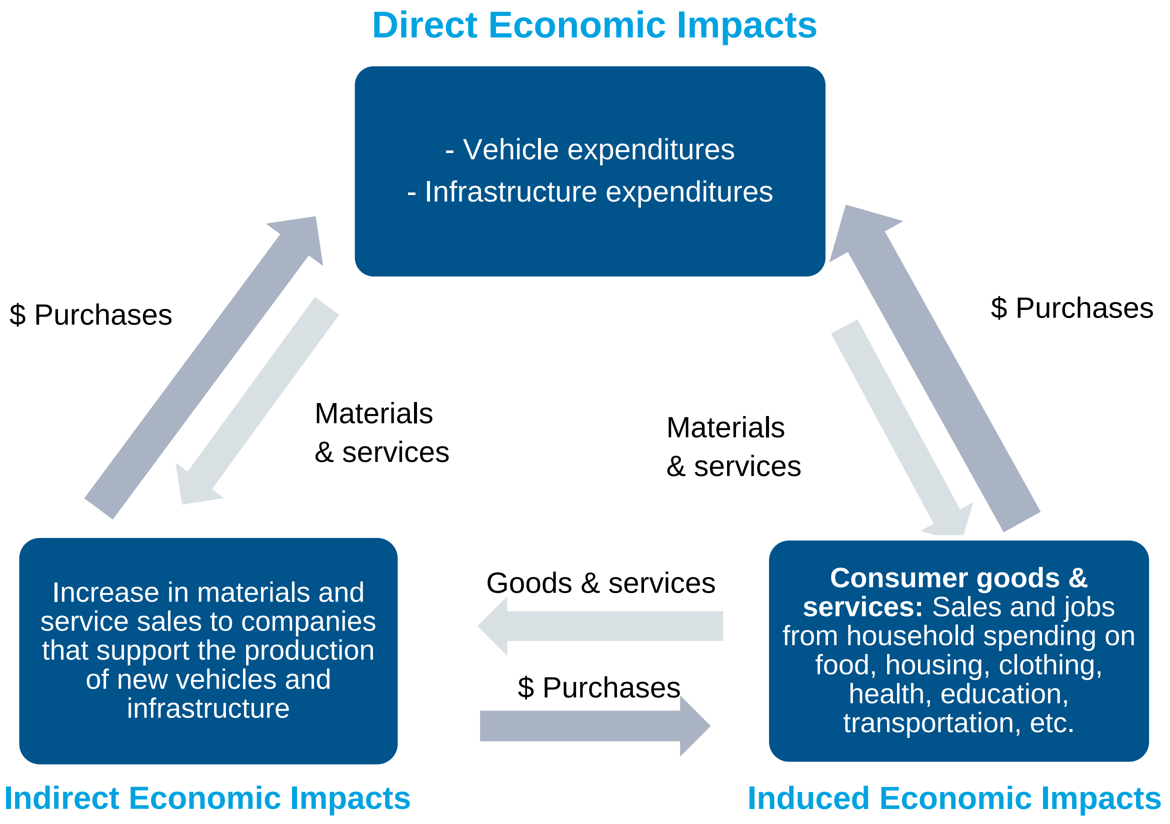
[1] IMPLAN is created and maintained by the Minnesota IMPLAN Group (MIG), http://www.implan.com

1. IMPLAN Model

The IMPLAN model is a static input-output framework used to analyze the effects of an economic stimulus on economic regions, in this case the State of California. The model includes 536 sectors based on the North American Industry Classification System (NAICS). As is depicted in Figure II-1, the model uses location-specific multipliers to trace and calculate the flow of dollars from the industries that originate the impact to supplier industries. As defined in IMPLAN, these multipliers are coefficients that “describe the response of the economy to a stimulus (a change in demand or production).” IMPLAN’s outputs include three types of economic impacts, which are described below and shown in Figure II-1.

- **Direct impacts**: Impacts in the primary industries where spending by trucking and construction firms is focused, such as engineering, truck manufacturing, and non-residential construction.
- **Indirect impacts**: Impacts in the industries that supply or interact with the primary industries, for example when building electric charging stations requires the purchase of construction-related building materials.
- **Induced impacts**: Impacts that represent increased spending by workers who earn money due to the proposed projects, such as when construction workers patronize local restaurants.

Figure II-1. IMPLAN Model Flow Diagram



The total impact is the sum resulting from multiple rounds of secondary indirect and induced impacts that remain in the region (as opposed to “leaking out” to other regions). IMPLAN then uses this total impact to calculate subsequent impacts such as total jobs created and tax revenues.

2. Model Inputs

The total economic impact of a scenario is driven by activity in three key categories: vehicle expenditures, vehicle fueling infrastructure development, and fuel spending/savings relative to diesel fuel. Vehicle expenditures include the cost of different classes of alternative fuel vehicles and the number of vehicles in each class that would be purchased in each scenario. Vehicle costs, taken from the Total Cost of Ownership Technology Assessment, vary year by year from 2019 to 2050. Infrastructure development expenditures are also taken from the Technology Assessment and are based on the number of fueling stations constructed and the cost of operating those stations from 2019 to 2050.

ICF mapped total annual vehicle and infrastructure expenditures to IMPLAN sectors to specify the different industries directly impacted by each activity. Because the materials needed to manufacture charging stations for BEVs are different from the materials needed for natural gas stations for NGVs, expenditures for the two types of stations were modeled separately. Similarly, the materials needed to build a BEV are different from a vehicle that runs on diesel, natural gas, or gasoline fuel.

IMPLAN “margins” allow expenditures to be traced through retail, wholesale, and transportation sectors back to the manufacturer. This level of detail allows activity to be appropriately attributed to the producing industries[2]. To account for the fact that spending on new vehicles and infrastructure directly impacts the manufacturing sector as well as retail dealers and wholesale traders, margins were included where available for vehicle and infrastructure activity sectors. Margins are not available for heavy-duty truck manufacturing, so the margins for a similar industry, automobile manufacturing, were applied.

Fuel costs were modeled as both spending on fuel and as savings due to avoided diesel and gasoline fuel costs. Spending on fuel was modeled as spending on diesel, natural gas, gasoline, and electricity, inclusive of generation, transmission, and distribution of the fuels.

Due to the nature and structure of IMPLAN, modeling how reduced fuel spending in the transportation sector affects the broader economy requires an intricate approach. Modeling the impacts of reduced revenue (due to fuels not purchased) on fuel-producing sectors is more straightforward and can be modeled in IMPLAN using a decrease in sales or by comparing a baseline level of sales with the sales under a certain policy. Appendix C describes in detail how fuel spending and fuel savings were treated in this analysis.

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[2] IMPLAN, 2015.

3. Output Metrics

As noted above, the results of this analysis are reported using four commonly used metrics—employment, labor income, gross regional product, and industry activity. Please note that employment results are presented in job-years,[3] not total jobs. For example, if the analysis period is 30 years and 300,000 job-years were created, the correct way to interpret the result is as approximately 10,000 annual jobs in each year, on average.

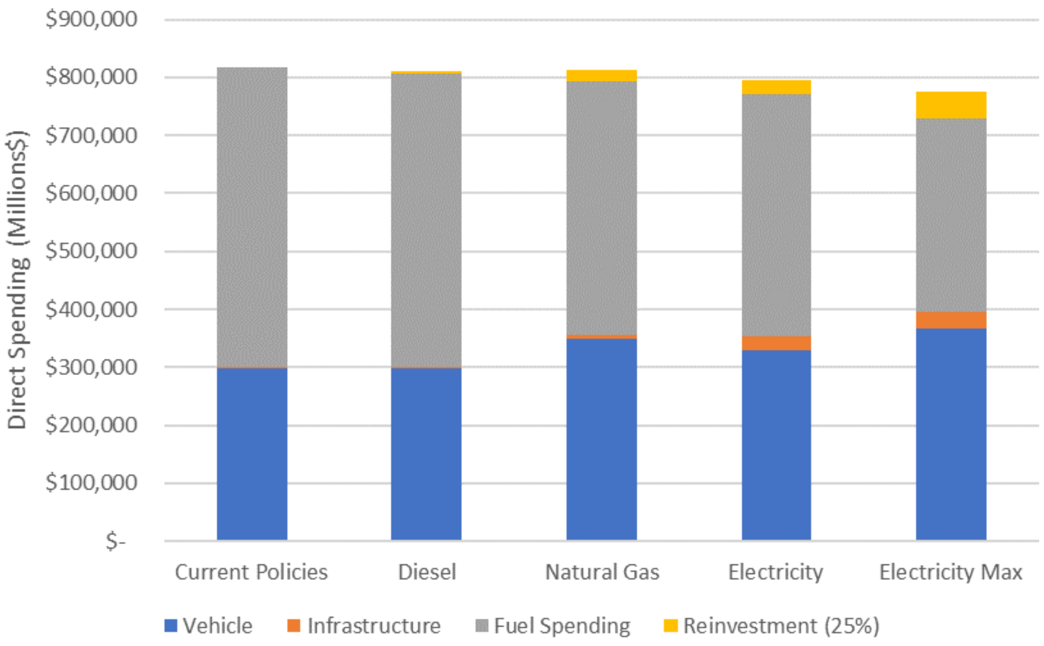
III. Results

This section presents the results of the Economic Analysis and is divided into Total Direct Spending, Employment, Labor Income, Gross Regional Product, and Industry Activity.

1. Total Direct Spending

Figure III-1 shows for each scenario the cumulative direct spending on vehicles, infrastructure, fuel, and reinvestment of fuel savings from 2019 to 2050.

Figure III-1. Cumulative Direct Spending



To better understand the relative impact of each scenario compared to the Current Policies scenario, Figure III-2 shows cumulative direct spending relative to the Current Policies scenario.

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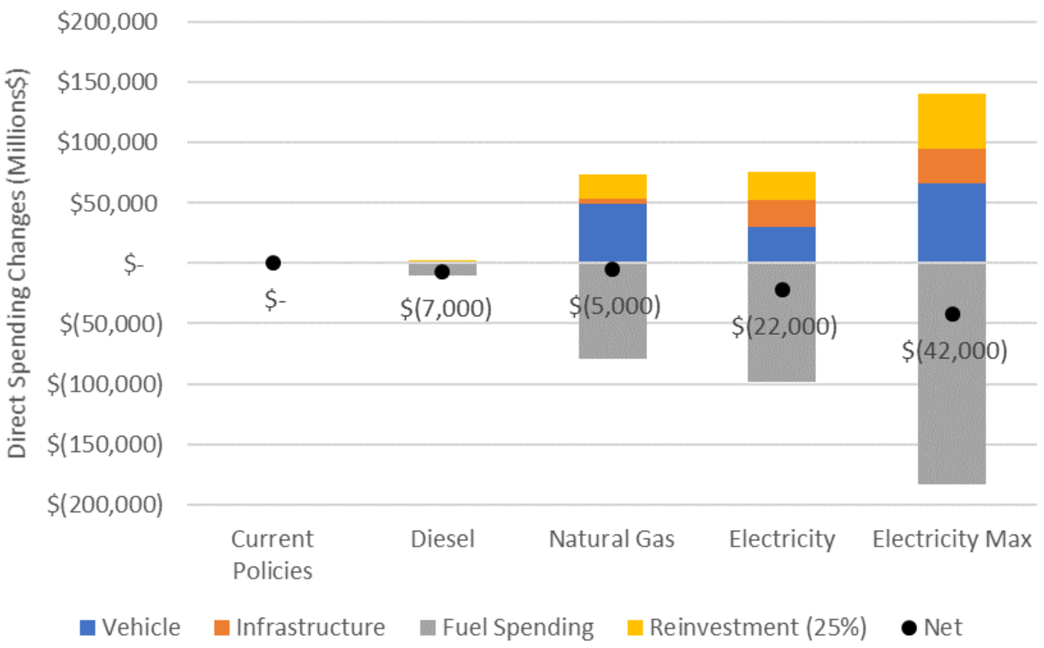
[3] IMPLAN job-years are similar to 2,080-hour full-time equivalent (FTE) jobs, but vary slightly by industry. Job-years represent the average hours worked by an employee in that industry in one year.

Figure III-2. Cumulative Direct Spending Relative to the Current Policies Scenario

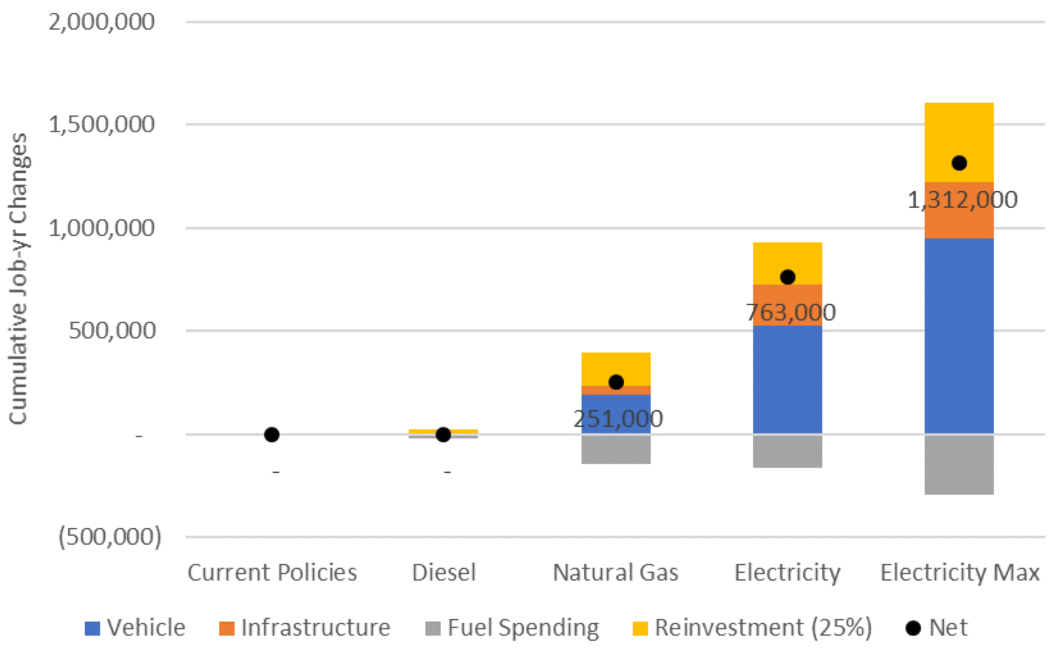


All scenarios have significantly reduced fuel spending compared to the Current Policies scenario. Also, compared to the Current Policies scenario, the Electricity and Electricity Max Scenarios show significant infrastructure spending and reinvestment of fuel savings. The higher cumulative fuel savings in the Electricity and Electricity Max scenarios are due to the higher per vehicle fuel savings from EVs compared to NGVs.

2. Employment

Figure III-3 shows the cumulative employment impacts for each scenario relative to the Current Policies scenario. It is important to keep in mind that a job-year is not directly equivalent to a new job, but rather is a full-time work opportunity for one person for one year. For example, 1,000 newly created jobs that return each year for a 30-year period would result in 30,000 job-years.

Figure III-3. Cumulative Job-Years for Each Scenario Relative to the Current Policies



The employment changes presented above combine direct, indirect, and induced changes relative to the Current Policies scenario of 1.66 million job-years from 2019 to 2050. The Electricity Scenario, which includes approximately 100,000 BEVs in 2030, resulted in 50% greater incremental employment per dollar of direct spending than the Natural Gas scenario. For all alternative fuel scenarios, the reinvestment of fuel savings offsets job losses from reduced fuel spending, resulting in almost net zero in employment impacts. Approximately 4 to 5 times as many job-years are created per dollar from reinvestment compared to job losses from fuel spending decreases. This is due to the sectors responsible for the production of conventional fuel having a much lower LPC (roughly 48% on average) than the sectors benefiting from fuel savings (roughly 84% average LPC), combined with output-per-worker in industries that produce fuel being, on average, higher than those that use fuel as an input.

Table III-1 shows the top 5 sectors for employment change from each spending category and for each fuel scenario. The underlined sectors have increased job-years compared to the Current Policies scenario, and sectors in bold have decreased job-years.[4]

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[4] Appendix B – Employment Detailed Results includes the detailed results for all of the spending categories and at least the top 10 categories for each spending category and scenario.

Table III-1. Top 5 Employment Change Categories by Spending Type

Spending Category	Diesel	Natural Gas	BEV	BEV Max
Vehicle[5]	No Change	• Retail – Motor vehicle and parts dealers • Wholesale trade • Real estate • Storage battery manufacturing • Full-service restaurants	• Retail – Motor vehicle and parts dealers • Wholesale trade • **Metal tank manufacturing** • Storage battery manufacturing • Real estate	
Infrastructure[6]	No Change	• Construction • Wholesale trade • Retail – Misc. stores • Full-service restaurants • Real estate	• Construction • Retail – Misc. stores • Wholesale trade • Architectural, engineering, related services • Retail – Electronics and appliance supplies	
Fuel Spending[7]	• **Retail gasoline** • **Wholesale trade** • **Extraction of NG and Crude** • **Real estate** • **Full-service restaurant**		• **Retail Gasoline** • **Wholesale trade** • **Extraction of NG and Crude** • Electric power generation • Marketing research	
Reinvestment[8]	• Truck transportation • Retail – Food and beverage stores • Retail – Misc. stores • Landscape and horticulture • Wholesale trade			
Total	• Truck transportation • Retail – Food and beverage stores • **Retail – Gasoline stores** • Retail – Misc. stores • Landscape and horticulture	• Truck transportation • Retail – Motor vehicle and parts dealers • Retail – Food and beverage stores • **Retail – Gasoline stores** • Retail – Misc. stores	• Retail – Motor vehicle and parts dealers • Truck transportation • Construction of other non-commercial structures • **Retail – Gasoline stores** • Retail – Misc. stores	• Retail – Motor vehicle and parts dealers • Truck transportation • **Retail – Gasoline stores** • Construction of other non-commercial structures • Retail – Misc. stores

Note: **Bold** = sectors with job losses; Underline = sectors with job gains

In general, the affected sectors are relatively similar across the spending categories, with mainly a reshuffling of the prioritization of sectors.

To quantify the relative employment impact of direct spending on vehicles and infrastructure, Table III-2 shows the employment impacts, direct spending, and ratio of employment to direct spending for both vehicles and infrastructure.

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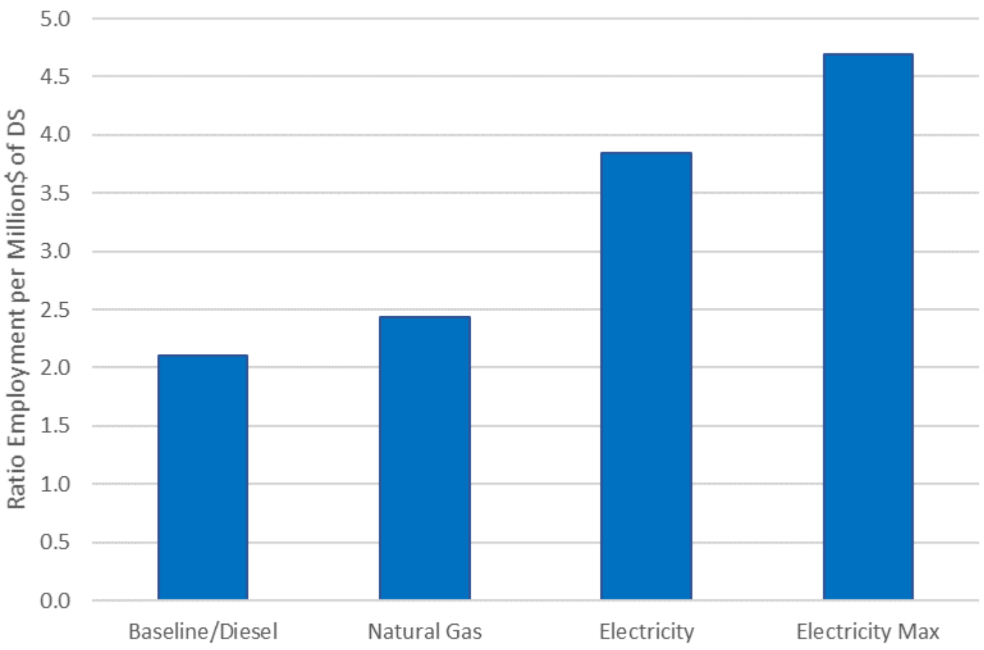
[5] Fuel spending categories are shared for BEV and BEV Max.
[6] Infrastructure categories are shared for BEV and BEV Max.
[7] Fuel spending categories are shared for Diesel and Natural Gas and for BEV and BEV Max.
[8] Reinvestment categories are shared for all scenarios.

Table III-2. Vehicle and Infrastructure Comparison of Employment and Direct Spending

Scenario	Vehicle and Infrastructure Employment	Cumulative Vehicle and Infrastructure Direct Spending	Ratio of Employment to Million$ Direct Spending
Baseline/Diesel	630,012	$300,101	2.1
Natural Gas	864,868	$354,467	2.4
BEV	1,355,326	$352,437	3.8
BEV Max	1,851,520	$394,969	4.7

Table III-2 and Figure III-4 show that the Electricity and Electricity Max scenarios have the highest impact on employment in California per dollar of direct spending on vehicles and infrastructure. The increase in employment and output between the Electricity and Electricity Max scenarios is due to the aggressive increase in deployment in the Electricity Max scenario.

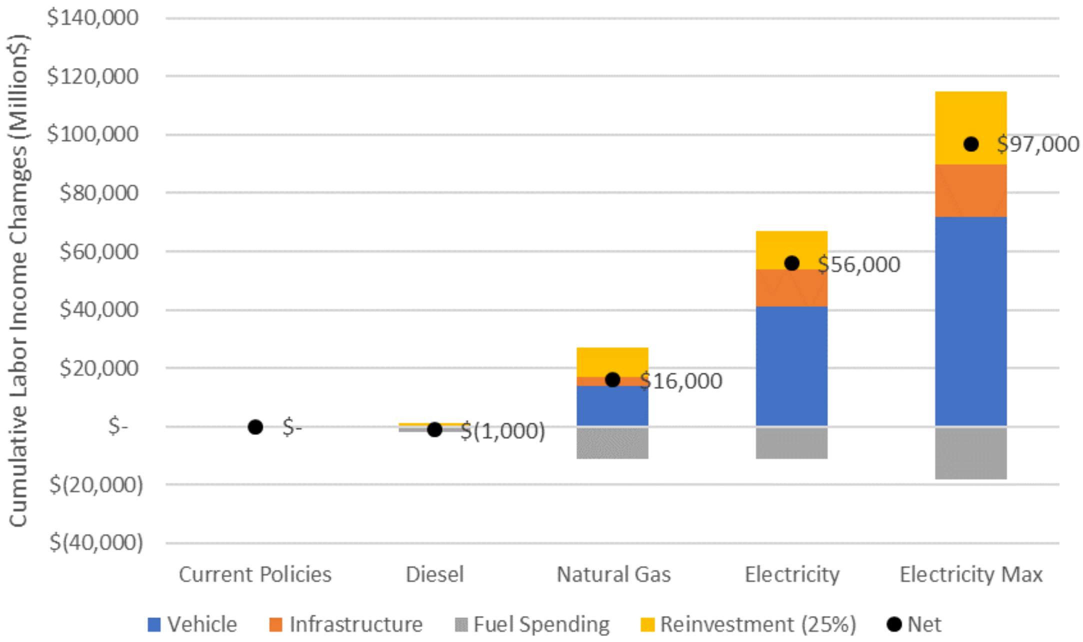
Figure III-4. Ratio of Employment to Direct Spending (Job-years/Million$)



3. Labor Income

Figure III-5 presents the cumulative changes in labor income relative to the Current Policies scenario, between 2019 and 2050.

Figure III-5. Cumulative Labor Income Relative to the Current Policies Scenario



The overall trend and trajectories are similar to the employment job-years shown in Figure III-3. To put the values in perspective, California total wages are approximately $2.5 trillion per year.[9] With an analysis period of approximately 30 years, this analysis projects approximately $500 million to $3.2 billion per year in increased labor income, or around 0.02% to 0.1% annual change in 2019 labor income.

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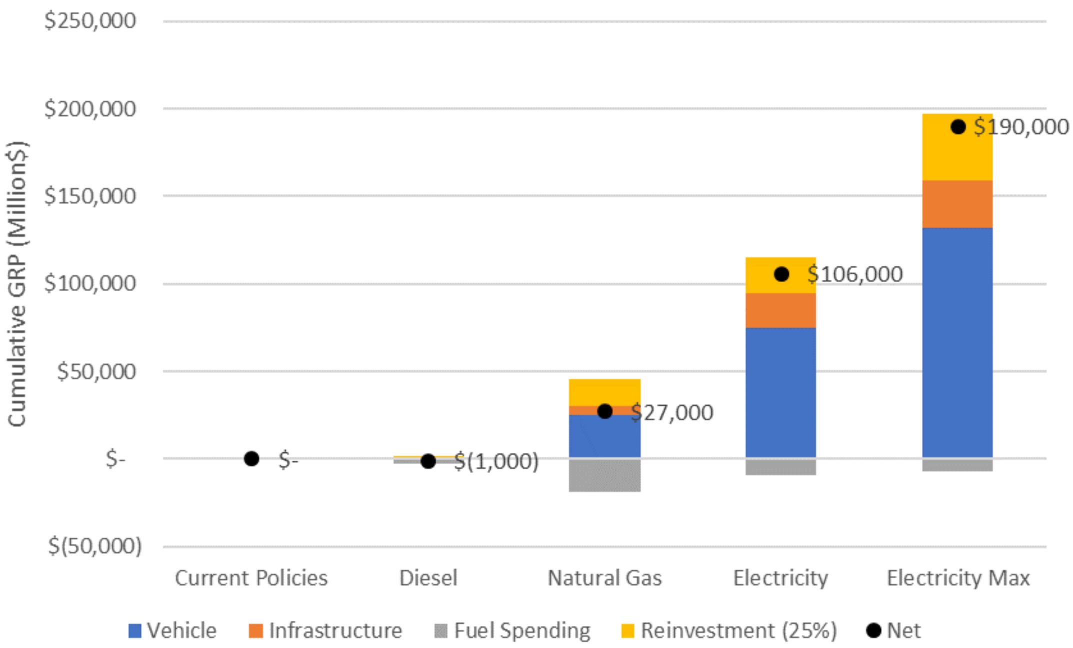
[9] BEA, 2019

4. Gross Regional Product

Figure III-6 shows the changes in GRP relative to the Current Policies scenario for the four spending categories. Because the boundaries of the analysis were drawn around the State of California, the GRP in this analysis is synonymous with California Gross State Product (GSP).

Figure III-6. Cumulative Changes in the GRP Relative to the Current Policies Scenario



The GRP changes shown in Figure III-6 are relative to the cumulative Current Policies GRP modeled impact of $82 billion from 2019 to 2050.[10] For comparison, the GSP for California in 2018 was $3.0 trillion.[11] The annualized increases in GRP range from 0.01% to 0.2% of current GSP. GRP increases from reinvestment of fuel savings more than offset GRP losses from reduced fuel spending. This is mainly due to the low LPC factors for the types of fuels that experience reductions in spending and high LPC factors for the industries and sectors spurred by reinvestment of fuel savings. The Electricity and Electricity Max Scenarios result in a more than doubling of GRP in the MD/HD truck sector.

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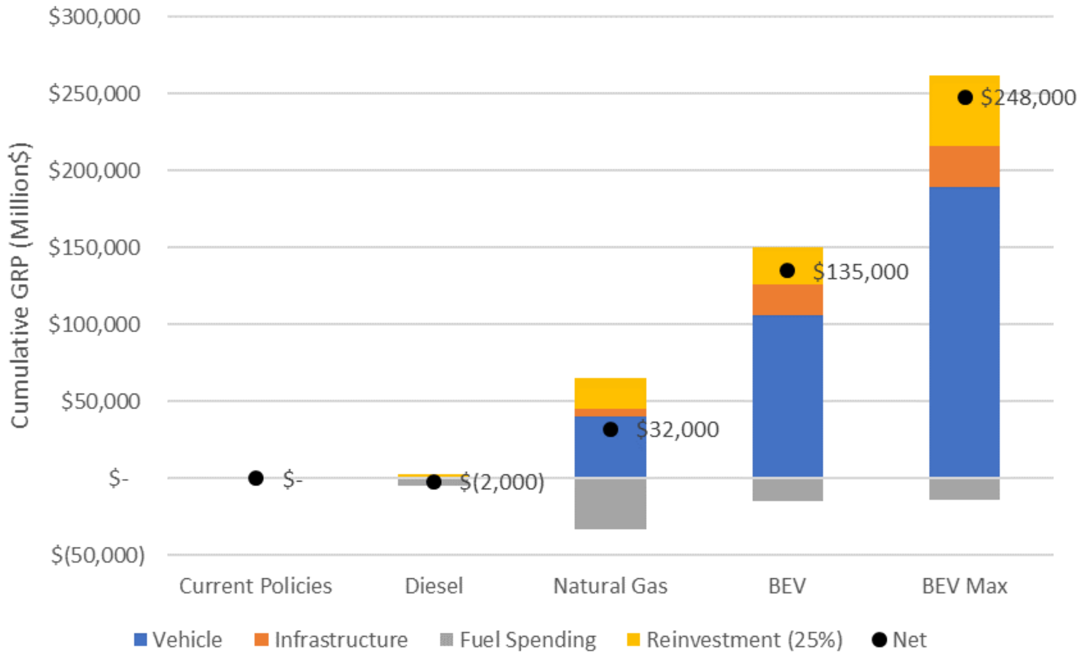
[10] Modeled impact is only for the MD/HD transportation sector from the Scenario Analysis.

[11] Department of Finance (DOF), 2019.

5. Industry Activity

Figure III-7 shows the changes in Industry Activity, as defined in Section II-3, Output Metrics, relative to the Current Policies scenario.

Figure III-7. Cumulative Industrial Activity Changes Relative to the Current Policies Scenario



The Industrial Activity changes shown in Figure III-7 are relative to the cumulative Current Policies impact of $131 billion in 2019–2050. The Electricity and Electricity Max scenarios result in a more than doubling of Industrial Activity in the MD/HD truck sector compared to the Current Policies scenario. Industrial Activity increases from reinvestment of fuel savings significantly more than offset losses from reduced fuel spending for the same reasons as discussed in the GRP section, due to the LPC factors and leakage[12] of spent dollars outside of California for conventional fuels.

IV. Conclusions

Increased adoption of alternative fueled vehicles results in net overall increases in employment, gross regional product (GRP) and industrial activity in California. While decreased fossil fuel consumption could reduce employment in retail gasoline stores and the natural gas and crude petroleum extraction sectors, much greater increases in employment occur in other sectors of the economy, resulting in net employment gains for California. Investment in battery electric vehicles and charging infrastructure results in greater employment, gross regional product

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[12] Leakage is the flow of spending from inside to outside of the analysis region, in this case California, resulting in no additional impact within the analysis region from that flow.

(GRP), and industrial activity per dollar spent compared to natural gas vehicles (NGVs) and NGV infrastructure.

All scenarios have significant reductions in fuel spending, and the Natural Gas, Electricity and Electricity Max Scenarios show significant investment in infrastructure, vehicles, and reinvestment opportunity compared to the Current Policies scenario. The three alternative fuel scenarios, Natural Gas, Electricity and Electricity Max, also result in employment increases and overall net decreases in direct spending. The job increases from fuel savings more than offset job losses from reduced fuel spending, resulting in almost net zero in employment impacts from reduced fuel spending and reinvestment of fuel savings.

The Electricity and Electricity Max Scenarios resulted in the highest employment, labor income, GRP, and industrial activity relative to the Current Policies scenario. The Electricity Scenario, which includes approximately 100,000 BEVs in 2030, resulted in a 50% increase in employment per dollar of direct spending compared to the Natural Gas scenario. Increased implementation of BEVs in the Electricity Max Scenario resulted in even higher employment per dollar of direct spending than the Electricity Scenario. This shows that BEV implementation past the Electricity Scenario would result in additional positive net economic impacts.

V. Appendix A – Main IMPLAN Factors

This appendix presents the main constituents for breaking down expenditures and LPCs for those constituents.

Table V-1. Diesel and Natural Gas IMPLAN Fuel Expenditure Sector Values

Sector Code	Sector	Constituent Percent[13, 14]	LPC Percent
156	Petroleum refineries	15%	88.58%
402	Retail – Gasoline stores	9%	97.61%
395	Wholesale trade	9%	99.99%
20	Extraction of natural gas and crude petroleum	50%	10.89%
0	Taxes – Not modeled	17%	

Table V-2. Gasoline IMPLAN Fuel Expenditure Sector Values

Sector Code	Sector	Constituent Percent[15, 16]	LPC Percent
402	Retail – Gasoline stores	7%	97.61%
395	Wholesale trade	7%	99.99%
156	Petroleum refineries	13%	88.58%
20	Extraction of natural gas and crude petroleum	57%	10.89%
0	Taxes – Not modeled	17%	

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[13] EIA, 2019a.
[14] Amount without taxes were recalculated to be 100% for the modeling.
[15] EIA, 2019b.
[16] Amount without taxes were recalculated to be 100% for the modeling.

Table V-3. Electricity IMPLAN Fuel Expenditure Sector Values

Sector Code	Sector	Constituent Percent[17]	LPC Percent[18]
49	Electric power transmission and distribution	40%[19]	23.63%
41	Electric power generation – Hydroelectric	17%	99.99%
42	Electric power generation – Fossil fuel	16%	96.32%
43	Electric power generation – Nuclear	6%	70.69%
44	Electric power generation – Solar	5%	83.81%
45	Electric power generation – Wind	5%	43.04%
46	Electric power generation – Geothermal	5%	88.90%
47	Electric power generation – Biomass	5%	88.10%

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[17] EIA, 2018 – Non-transmission and distribution factors.
[18] CEC, 2019.
[19] EIA, 2019c.

Table V-4. Fuel Savings Investment Sector Values

Sector Code	Sector	Constituent Percent	LPC Percent
411	Truck transportation	36%	95.59%
49	Electric power transmission and distribution	7%	23.63%
427	Wired telecommunications carriers	7%	88.96%
50	Natural gas distribution	7%	99.99%
400	Retail – Food and beverage stores	5%	100.00%
105	All other food manufacturing	5%	57.12%
463	Facilities support services	3%	65.90%
469	Landscape	3%	99.63%
470	Other support services	3%	91.26%
406	Retail – Miscellaneous store retailers	3%	99.94%
395	Wholesale trade	3%	99.99%
52	Construction of new health care structures	1%	100.00%
53	Construction of new manufacturing structures	1%	100.00%
54	Construction of new power and communication structures	1%	100.00%
55	Construction of new educational and vocational structures	1%	99.85%
56	Construction of new highways and streets	1%	99.99%
57	Construction of new commercial structures, including farm structures	1%	100.00%
58	Construction of other new nonresidential structures	1%	99.95%
59	Construction of new single-family residential structures	1%	100.00%
60	Construction of new multifamily residential structures	1%	99.99%
61	Construction of other new residential structures	1%	100.00%
156	Petroleum refineries	3%	88.58%
20	Extraction of natural gas and crude petroleum	3%	10.89%
471	Waste management and remediation services	4%	98.27%
394	All other miscellaneous manufacturing	4%	35.99%

Table V-5. Natural Gas Station IMPLAN Expenditure Sector Values

Cost Type	Sector Code	Description	Percent of Total Cost	LPC Percent
Compressor	288	Air and gas compressor manufacturing	24%	5.40%
Dispenser	271	All other industrial machinery manufacturing	14%	20.83%
Dryer	271	All other industrial machinery manufacturing	3%	20.83%
Storage	244	Metal tank (heavy gauge) manufacturing	22%	8.05%
Card reader	271	All other industrial machinery manufacturing	1%	20.83%
Vaporizer	271	All other industrial machinery manufacturing	7%	20.83%
Other	271	All other industrial machinery manufacturing	14%	20.83%
Engineering	449	Architectural, engineering, and related services	14%	95.15%
Installation	58	Construction of other new nonresidential structures	100%	99.95%

Table V-6. Electric Charging Station IMPLAN Expenditure Sector Values

Cost Type	Sector Code	Description	Percent of Total Cost	LPC Percent
Engineering	449	Architectural, engineering, and related services	16%	95.15%
Electric components	342	All other miscellaneous electrical equipment and component manufacturing	20%	21.52%
Other	271	All other industrial machinery manufacturing	64%	20.83%
Installation	58	Construction of other new nonresidential structures	100%	99.95%

Table V-7. Non-Electric Vehicle Expenditure Sector Values

Sector Code	Description	Percent of Total Cost	LPC Percent
Class 2b			
244	Metal tank (heavy gauge) manufacturing	65%	8.05%
344	Light truck and utility vehicle manufacturing	15%	3.11%
356	Other motor vehicle parts manufacturing	20%	19.01%
Non-Class 2b			
244	Metal tank (heavy gauge) manufacturing	65.00%	8.05%
345	Heavy-duty truck manufacturing	10.50%	23.72%
396	Retail – Motor vehicle and parts dealers	2.98%	96.23%
395	Wholesale trade	1.22%	99.99%
411	Truck transportation	0.17%	95.59%
409	Rail transportation	0.12%	48.55%
408	Air transportation	0.00%	71.62%
356	Other motor vehicle parts manufacturing	20%	19.01%

Table V-8. Electric Vehicle Expenditure Sector Values in 2019

Sector Code	Description	Percent of Total Cost	LPC Percent
Class 2b			
336	Storage battery manufacturing	39.00%	27.24%
344	Light truck and utility vehicle manufacturing	26.14%	3.11%
356	Other motor vehicle parts manufacturing	34.86%	19.01%
Non-Class 2b			
336	Storage battery manufacturing	39.00%	27.24%
345	Heavy-duty truck manufacturing	18.30%	8.05%
396	Retail – Motor vehicle and parts dealers	5.19%	23.72%
395	Wholesale trade	2.13%	96.23%
411	Truck transportation	0.30%	99.99%
409	Rail transportation	0.22%	95.59%
408	Air transportation	0.01%	48.55%
356	Other motor vehicle parts manufacturing	34.86%	71.62%

Table V-9. Electric Vehicle Expenditure Sector Values in 2032

Sector Code	Description	Percent of Total Cost	LPC Percent
Class 2b			
336	Storage battery manufacturing	30.30%	27.24%
344	Light truck and utility vehicle manufacturing	29.87%	3.11%
356	Other motor vehicle parts manufacturing	39.83%	19.01%
Non-Class 2b			
336	Storage battery manufacturing	30.30%	27.24%
345	Heavy-duty truck manufacturing	20.91%	8.05%
396	Retail – Motor vehicle and parts dealers	5.93%	23.72%
395	Wholesale trade	2.44%	96.23%
411	Truck transportation	0.34%	99.99%
409	Rail transportation	0.25%	95.59%
408	Air transportation	0.01%	48.55%
356	Other motor vehicle parts manufacturing	39.83%	71.62%

VI. Appendix B – Employment Detailed Results

Table VI-1. Employment Changes Relative to Current Policies from Fuel Spending (Job-years)

	Diesel	Natural Gas	BEV	BEV Max
Retail – Gasoline stores	(5,695)	(42,025)	(84,086)	(173,041)
Wholesale trade	(3,745)	(27,518)	(51,781)	(105,716)
Extraction of natural gas and crude petroleum	(1,238)	(10,051)	(19,239)	(40,995)
Limited-service restaurants	(367)	(2,736)	(5,447)	(11,276)
Real estate	(596)	(4,258)	(5,020)	(9,108)
Warehousing and storage	(257)	(1,900)	(3,798)	(7,836)
Management of companies and enterprises	(244)	(1,837)	(3,644)	(7,558)
Individual and family services	(221)	(2,386)	(2,859)	(5,685)
Full-service restaurants	(400)	(2,695)	544	3,244
Employment services	(286)	(1,875)	1,274	4,445
Maintenance and repair construction of nonresidential structures	–	920	3,659	8,657
Scenic and sightseeing transportation and support activities for transportation	–	218	4,849	11,620
Marketing research and all other miscellaneous professional, scientific, and technical services	–	348	7,746	18,561
Electric Power Generation	–	858	19,109	45,791

Table VI-2. Employment Changes Relative to Current Policies from Reinvestment (Job-years)

	Diesel	Natural Gas	BEV	BEV Max
Truck transportation	4,825	37,016	46,032	87,695
Retail – Food and beverage stores	1,626	12,503	15,511	29,341
Retail – Miscellaneous store retailers	1,307	10,046	12,470	23,629
Landscape and horticultural services	932	7,151	8,893	16,941
Wholesale trade	685	5,257	6,535	12,439
Other support services	581	4,454	5,547	10,614

	Diesel	Natural Gas	BEV	BEV Max
Couriers and messengers	444	3,407	4,237	8,070
Real estate	440	3,375	4,196	7,987
Waste management and remediation services	407	3,114	3,881	7,443
Full-service restaurants	365	2,802	3,485	6,640

Table VI-3. Employment Changes Relative to Current Policies from Infrastructure Spending (Job-years)

	Diesel	Natural Gas	BEV	BEV Max
Construction of other new nonresidential structures	0	25,200	89,100	119,800
Retail – Miscellaneous store retailers	0	900	15,300	22,700
Wholesale trade	0	1,300	6,100	8,600
Architectural, engineering, and related services	0	700	5,100	7,900
Retail – Electronics and appliance stores	0		5,000	7,900
Real estate	0	800	3,600	5,000
Full-service restaurants	0	800	3,400	4,700
Limited-service restaurants	0	700	3,000	4,100
Truck transportation	0	500	2,000	2,800
Employment services	0	400	2,000	2,900
Individual and family services	0	400		

Table VI-4. Employment Changes Relative to Current Policies from Vehicle Spending (Job-years)

	Diesel	Natural Gas	BEV	BEV Max
Retail – Motor vehicle and parts dealers		96,800	228,100	413,400
Wholesale trade		20,200	45,600	80,300
Storage battery manufacturing		5,300	16,300	28,900
Real estate		6,800	15,300	27,200
Full-service restaurants		4,700	10,300	18,300
Truck transportation		4,400	9,700	17,300
Limited-service restaurants		4,300	9,300	16,500

	Diesel	Natural Gas	BEV	BEV Max
Warehousing and storage		3,500	8,000	14,300
Employment services		3,500	7,300	13,100
Metal tank (heavy gauge) manufacturing			(26,500)	(43,900)
Other motor vehicle parts manufacturing		3,200		

VII. Appendix C - Treatment of Fuel Savings

Modeling the impacts of reduced fuel spending requires a more intricate approach due to a key limitation of the IMPLAN model: IMPLAN is a static-price model[20] that relies on sector-level relationships among output, wages, and employment. Production is modeled using industry spending patterns calculated from publicly available industry input-output tables. These patterns transform output in one sector into its constituent parts from other sectors, using coefficients that sum to 1. For example, one unit of furniture may be 0.25 units from the wood manufacturing sector, 0.25 units from the cloth manufacturing sector, etc.[21] IMPLAN does not account for price at any step. Instead, the relative importance of each sector’s contribution to the final product can be edited (for example, changing the coefficient on wood to 0.30). Modeling increases or decreases in production costs, such as fuel costs, presents a significant challenge due to these limitations. Because of these limitations, ICF used an alternative method to analyze the impact of fuel savings, further discussed below.

To model a decrease in fuel spending in sectors that use a significant portion of fuel in producing output, it is necessary to make assumptions about producer behavior when faced with changing prices. Faced with a decrease in price for one of its inputs — in this case, fuel — a producer may reinvest some of that savings into increased production (buying more inputs, hiring more workers, etc.). However, the “economies of scale” theory assumes that increased production of an output should also reduce the price of that output. How producers in each sector respond to a change in production costs can vary significantly. While a general equilibrium model could account for this, it is not possible to capture the interaction between relative prices in IMPLAN. Instead, we can assume a range of possible outcomes. We assume that producers could reinvest between 25% and 100% of the dollar value of their fuel savings into increased production of outputs.

To conservatively estimate the economic impact of fuel savings reinvestment, ICF assumed that relevant industries would reinvest 25% of total fuel savings into increased production by impacted industries (i.e. general freight, utilities and like services, packing, etc.). This is modeled in IMPLAN by adjusting the industry spending pattern for the relevant industry to zero out their spending on fuel costs. Then, an increase in industry sales equal to the selected percentage of the total fuel savings is modeled using this adjusted spending pattern. Using this method, only increases in purchases of intermediary products *other than* fuel are captured. Unfortunately, there are very few studies that estimate the fuel price elasticity of production, and those that exist are generally inconclusive. The remaining fuels savings are not accounted for in this analysis.

Modeling the impacts of fuels not purchased on fuel-producing sectors is more straightforward and can be modeled in IMPLAN using a decrease in sales or by comparing a baseline level of sales with the sales under a certain policy. The employment impacts from fuel savings and decreased sales of fuel necessitate further explanation of IMPLAN’s internal production

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[20] Static price models are not able to analyze the impact of a change in commodity price due to changes in supply or demand.

[21] The main IMPLAN sector breakdowns important to the analysis are presented in Appendix A – Main IMPLAN Factors.

methodology. In IMPLAN, when a specified dollar amount is modeled as an increase or decrease in sales, IMPLAN first uses local purchase coefficients (LPCs)[22] to split the total sales into sales that are produced within the region being studied and sales produced outside that region. These LPCs are estimated by IMPLAN using public data. The LPC for a given region is equal to the supply of a commodity (or total amount produced) in that region divided by the demand (or total amount purchased) in that region, capped at 100%. After the local portion of total sales is identified, these sales are translated into employment increases using output-per-worker estimates from U.S. Bureau of Economic Analysis (BEA) data. That is, total output in an industry divided by the total number of workers. Below, a simple equation shows how an initial increase in sales in sector *s* is translated to local employment in the IMPLAN model.

$$LocalEmployment_s = \frac{(SalesChange_s * LPC_s)}{TotalOutput_s/TotalEmployment_s}$$

In this analysis, the sectors responsible for the production of fuel have a much lower LPC (roughly 48% on average) than the sectors benefiting from fuel savings (roughly 84% average LPC). Similarly, output-per-worker in industries that produce fuel is, on average, higher than those that use fuel as an input. For example, IMPLAN’s output-per-worker for petroleum refineries is about $6.8 million annually. For an industry that relies on fuel, such as truck transportation, output-per-worker is estimated at about $157,000. Combining high output-per-worker with a low LPC means that it takes a significantly greater amount of sales to generate employment impacts in fuel-producing sectors as compared to fuel-using sectors with a low output-per-worker and a high LPC.

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[22] LPCs for the main sectors impacting the Economic Analysis are presented in Appendix A – Main IMPLAN Factors.

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Comparison of Medium- and Heavy-Duty Technologies in California

Part 4

Balanced Scorecard

December 2019

Submitted by:
ICF
75 East Santa Clara St.
Suite 600
San Jose, CA 95113

Prepared for:

California Electric Transportation Coalition
Natural Resources Defense Council

In Partnership With:
Union of Concerned Scientists
Earthjustice
BYD
Ceres
NextGen Climate America

With Advisory Support From:
University of California, Davis Policy Institute for Energy, Environment and the Economy
East Yard Communities for Environmental Justice

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Abbreviations and Acronyms

EV	electric vehicle
GHG	greenhouse gas
HVIP	Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project
LCFS	Low Carbon Fuel Standard
LFG	landfill gas
MD/HD	medium and heavy-duty
NG	natural gas
NOx	oxides of nitrogen
PM	particulate matter
RNG	renewable natural gas
TCO	total cost of ownership

I. Balanced Scorecard

Currently, scoring and ranking systems for many emission reduction and technology funding mechanisms focus on a singular pollutant or goal and determine cost-effectiveness around reducing that pollutant or meeting that goal (e.g., diesel particulate matter (PM) reduction policies). Sometimes, these previous frameworks have even favored fossil fuel technologies over advanced vehicle technologies because their analysis was limited in scope. With California's near-term and long-term goals for multiple pollutant reductions, it is necessary to be able to evaluate technologies not just for singular pollutant or emissions goals, but how they fit into the broader landscape of California regulatory policies. The objective of this portion of the project was to develop a framework, called the "Balanced Scorecard," to more easily compare different vehicle-fuel technologies across a number of dimensions including technical, economic, environmental, and regulatory considerations, using a combination of quantitative (if available) and qualitative factors. The Balanced Scorecard compares battery electric, hydrogen, natural gas (both fossil and RNG), diesel, and diesel substitutes (e.g., renewable diesel) in the various truck and bus market categories.

1. Balanced Scorecard Considerations

The Balanced Scorecard is divided into five sections and combines both quantitative and qualitative technological, economic, and policy assessments. The following are the five categories of the Balanced Scorecard:

- Commercialization status
- Barriers today
- Environmental considerations
- Policy alignment
- Cost considerations

The Balanced Scorecard is rated using a combination of qualitative and quantitative analytical and market assessments made by ICF, and then reported out using a five-color scheme. The five-color scheme is shown in the following spectrum—with red the lowest rating on the left and green the highest rating on the right.

Where appropriate, the analytical assessment will be reported out on an absolute basis in the context of the cell, but the rating will typically be determined on a relative basis. The text in Table I-1 provides direction regarding the key components of ICF's assessment for each element of the Balanced Scorecard.

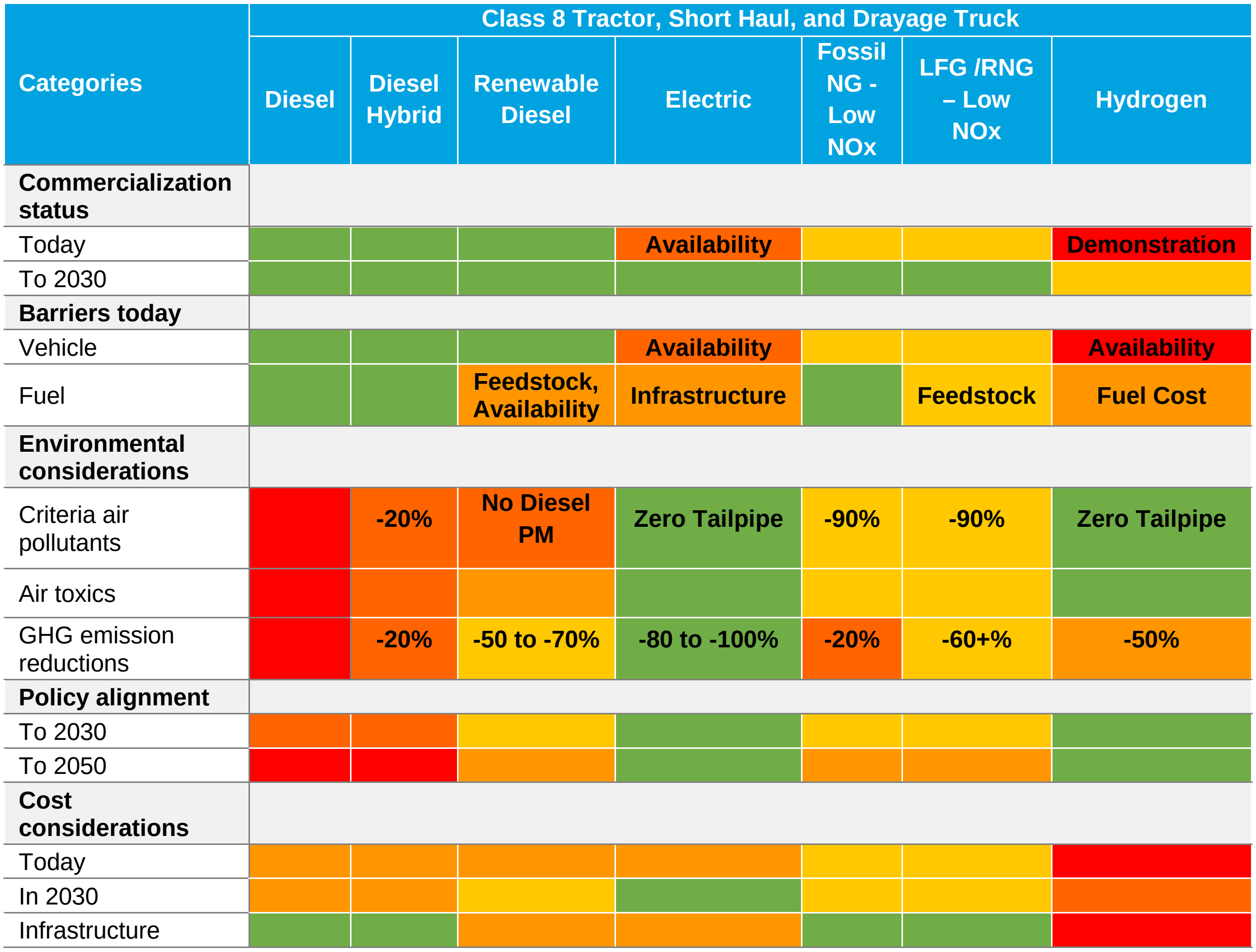
Table I-1. Balanced Scorecard Categories and Key Considerations

Categories	Worst >>>> Best				
Commercialization status	Qualitative assessment of ability of fleets to deploy vehicle technology at volume in the study jurisdiction (California), time to deliver that number of vehicles to fleet, number of vehicle/engine manufacturers capable of producing vehicles.				
Today	🟥	🟧	🟧	🟨	🟩
To 2030	🟥	🟧	🟧	🟨	🟩
Barriers today	*Vehicle*: Market assessment of vehicle technology in vocation of interest, including operator/fleet willingness to adopt technology, and over what timeframe that technology can be deployed. *Fuel production*: Market assessment of fuel production quantities and availability in California, current availability of fuel distribution infrastructure and fuel distribution technology.				
Vehicle	🟥	🟧	🟧	🟨	🟩
Fuel	🟥	🟧	🟧	🟨	🟩
Environmental considerations	Quantitative assessment of the emission reductions reported as an absolute percentage reduction compared to diesel, and subsequently categorized based on that according to corresponding buckets in the following cells.				
Criteria air pollutants	**<10%**	**10-35%**	**36-60%**	**61-90%**	**>90%**
Air toxics	**<10%**	**10-35%**	**36-60%**	**61-90%**	**>90%**
Greenhouse gas (GHG) emission reductions	**<10%**	**10-35%**	**36-60%**	**61-90%**	**>90%**
Policy alignment	Qualitative assessment of alignment with key policy goals in study jurisdiction (California), focused on transition to zero emission technologies to reduce criteria air pollutants to meet air quality goes in 2031, lower GHG emissions to meet 2030 and 2050 goals, and petroleum displacement potential.				
To 2030	🟥	🟧	🟧	🟨	🟩
To 2050	🟥	🟧	🟧	🟨	🟩
Cost considerations	Includes TCO, vehicle and infrastructure costs reported on an absolute basis for each vehicle-fuel relative to each other; the rating (color), however, is based on costs relative to availability of diesel.				
Today	🟥	🟧	🟧	🟨	🟩
In 2030	🟥	🟧	🟧	🟨	🟩
Infrastructure	🟥	🟧	🟧	🟨	🟩

2. Class 8 Tractor, Short Haul, and Drayage Truck Balanced Scorecard Example

Table I-2 provides an example of the application of the Balanced Scorecard to the Class 8 tractor, short haul and drayage truck applications.

Table I-2. **Class 8 Tractor, Short Haul, and Drayage Truck Balanced Scorecard**



Categories	Class 8 Tractor, Short Haul, and Drayage Truck						
	Diesel	Diesel Hybrid	Renewable Diesel	Electric	Fossil NG - Low NOx	LFG /RNG – Low NOx	Hydrogen
Commercialization status							
Today	🟩	🟩	🟩	Availability	🟨	🟨	Demonstration
To 2030	🟩	🟩	🟩	🟩	🟩	🟩	🟨
Barriers today							
Vehicle	🟩	🟩	🟩	Availability	🟨	🟨	Availability
Fuel	🟩	🟩	Feedstock, Availability	Infrastructure	🟩	Feedstock	Fuel Cost
Environmental considerations							
Criteria air pollutants	🟥	-20%	No Diesel PM	Zero Tailpipe	-90%	-90%	Zero Tailpipe
Air toxics	🟥	🟧	🟧	🟩	🟨	🟨	🟩
GHG emission reductions	🟥	-20%	-50 to -70%	-80 to -100%	-20%	-60+%	-50%
Policy alignment							
To 2030	🟧	🟧	🟨	🟩	🟨	🟨	🟩
To 2050	🟥	🟥	🟧	🟩	🟧	🟧	🟩
Cost considerations							
Today	🟧	🟧	🟧	🟧	🟨	🟨	🟥
In 2030	🟧	🟧	🟨	🟩	🟨	🟨	🟧
Infrastructure	🟩	🟩	🟧	🟧	🟩	🟩	🟥

In terms of commercialization status today, battery electric trucks in the above categories are lacking vehicle availability, and hydrogen Class 8 trucks are still in the demonstration stage. Natural gas Class 8 trucks were scored a light yellow in the above table for commercialization status today because of their incremental cost and the limited number of engine manufacturers (only Cummins is producing low-NOx engines). By 2030, all vehicle-technology combinations besides hydrogen are comparable to diesel on vehicle availability and deployment at volume. Hydrogen is expected to still have vehicle availability limitations in the 2030 timeframe.

In terms of barriers on the fuel side, there are currently cost and infrastructure limitations, respectively, for hydrogen and electricity. Renewable diesel and biodiesel also have feedstock availability and production limitations today such as not enough low carbon feedstock (e.g., used cooking oil, tallow) and renewable diesel production facilities. Similarly, for RNG / Landfill gas there is a feedstock and production barrier today for producing enough fuel to meet the demand from the MD/HD trucking sector. It is expected that RNG production could meet higher production volumes, but with limitation concerns for RNG from waste feedstocks that would be needed to be competitive in the LCFS, and the production facilities still need to be constructed. In addition, as explained in the Scenario Analysis, the lack of sufficient feedstock supply for RNG / LFG trucks to meet 2050 GHG goals is a long-term barrier. Regarding electric “fuel” for trucks today, infrastructure availability is the main barrier. The assumption of home base charging in this analysis still requires the implementation of charging infrastructure and utility upgrades to meet the potential demand. Electric truck charging requires much higher loads than light-duty EVs.

For environmental considerations, electric trucks can achieve significant reductions in all three categories and hydrogen in criteria pollutant and air toxics. The assumption that hydrogen is produced from steam methane reforming of LFG results in the assumed 50% reduction. Hydrogen produced from electrolysis by renewable power could achieve reductions to get into the green category but is not typically used due to its high cost. Natural gas trucks can significantly reduce air toxics and criteria pollutant emissions but not in excess of 90%. The reductions from using RNG are limited based upon the assumption that RNG is from landfill gas. Additional environmental considerations that could be added to a balanced scorecard include water pollution, water use, impact on food supply, direct and indirect land use change, soil erosion and pesticide use. Liquid biofuels in particular tend to have these issues.

In the policy alignment category, both hydrogen and electric trucks align with 2030 and 2050 policy goals by producing zero tailpipe emissions and significant GHG reductions. Natural gas, both RNG and fossil, can achieve significant criteria pollutant and air toxics reductions towards 2030 goals, but their GHG emission reduction potential can’t meet California’s 2050 goals (see the Scenario Analysis). A potential low-NOx truck regulation requiring low-NOx diesel engines could slightly help achieve 2030 criteria pollutant goals. For 2030 goals, low-NOx technology in trucks using renewable diesel, fossil NG or renewable NG can achieve similar reductions.

Lastly, cost considerations, including TCO and capital costs, put hydrogen in the red for today and still the dark orange for 2030. Today’s electric trucks scored a mid-orange color due to their high overall incremental cost that required an HVIP incentive to be cost competitive, combined with their lower operating and fuel costs. In 2030, hydrogen drops from the red to the dark orange and electric from the mid-orange to green as the incremental costs substantially decrease and electric trucks have lower TCOs without HVIP incentives. For infrastructure, the costs and ability to implement diesel and natural gas infrastructure is well known and documented which results in a green score. Renewable diesel still needs significant infrastructure expansion to include fuel production, and electric truck infrastructure will require higher load charging likely needing electric system upgrades such that both are scored a mid-orange color. Renewable natural gas infrastructure scores a green color. Not enough data exists for this report to analyze Plug-in Hybrid Electric truck costs.

3. Conclusions

From the Balanced Scorecard for Class 8 trucks, we are able to see that both electric and hydrogen show the greatest potential for meeting our near- and long-term policy goals and that RNG and renewable diesel could have a role to play in the meeting the near-term 2030 goals. Electric and hydrogen trucks still have near-term commercialization barriers related to cost and availability. The current HVIP incentive program is the main reason Class 8 trucks are cost competitive on a TCO basis right now, but in 2030 or sooner Class 8 electric trucks have the best TCO even without the HVIP incentive. This full and comprehensive view allows the reader, and policymakers, to get a more complete and nuanced comparison of the vehicle-fuel combinations.

One element that is not directly addressed in the scorecard, but is something to consider, is adaptation, especially by smaller fleets. Electric truck users will need to acclimate to the transition from refueling, which can happen at any point during the day, to charging around their own utilities rate structures. An adjustment from existing driving/work patterns will likely be a barrier to short-term expansive electrification.

II. Appendix A – Balanced Scorecards

1. Class 8 Refuse and Class 6 Regional Haul

Table II-1. Class 8 Refuse and Class 6 Regional Haul Balanced Scorecard

Categories	Class 8 Refuse and Class 6 Regional Haul				
	Diesel	Renewable Diesel	Electric	Fossil NG -Low NOx	RNG – Low NOx
Commercialization status					
Today	🟩	🟩	**Availability**	🟨	🟨
To 2030	🟩	🟩	🟩	🟩	🟩
Barriers today					
Vehicle	🟩	🟩	**Availability**	🟨	🟨
Fuel	🟩	**Feedstock, Availability**	**Infrastructure**	🟩	**Feedstock**
Environmental considerations					
Criteria air pollutants	🟥	**No Diesel PM**	**Zero Tailpipe**	**-90%**	**-90%**
Air toxics	🟥	🟧	🟩	🟨	🟨
GHG emission reductions	🟥	**-50 to -70%**	**-80 to -100%**	**-20%**	**-60+%**
Policy alignment					
To 2030	🟧	🟨	🟩	🟨	🟨
To 2050	🟥	🟧	🟩	🟧	🟧
Cost considerations					
Today	🟧	🟧	🟧	🟨	🟨
In 2030	🟧	🟨	🟨	🟨	🟨
Infrastructure	🟩	🟧	🟧	🟩	🟩

Compared to the Class 8 technologies presented in the Balanced Scorecard in Table II-2, the main differences are in capital costs. The electric trucks for regional haul and refuse applications were moved to be a shade darker in Today and 2030 due to the higher incremental costs of the vehicles (especially for regional haul trucks). However, in 2030 electric trucks in these categories have a significant TCO advantage without HVIP incentives (especially for refuse trucks).

2. Class 6 Urban Delivery and Class 2b-5

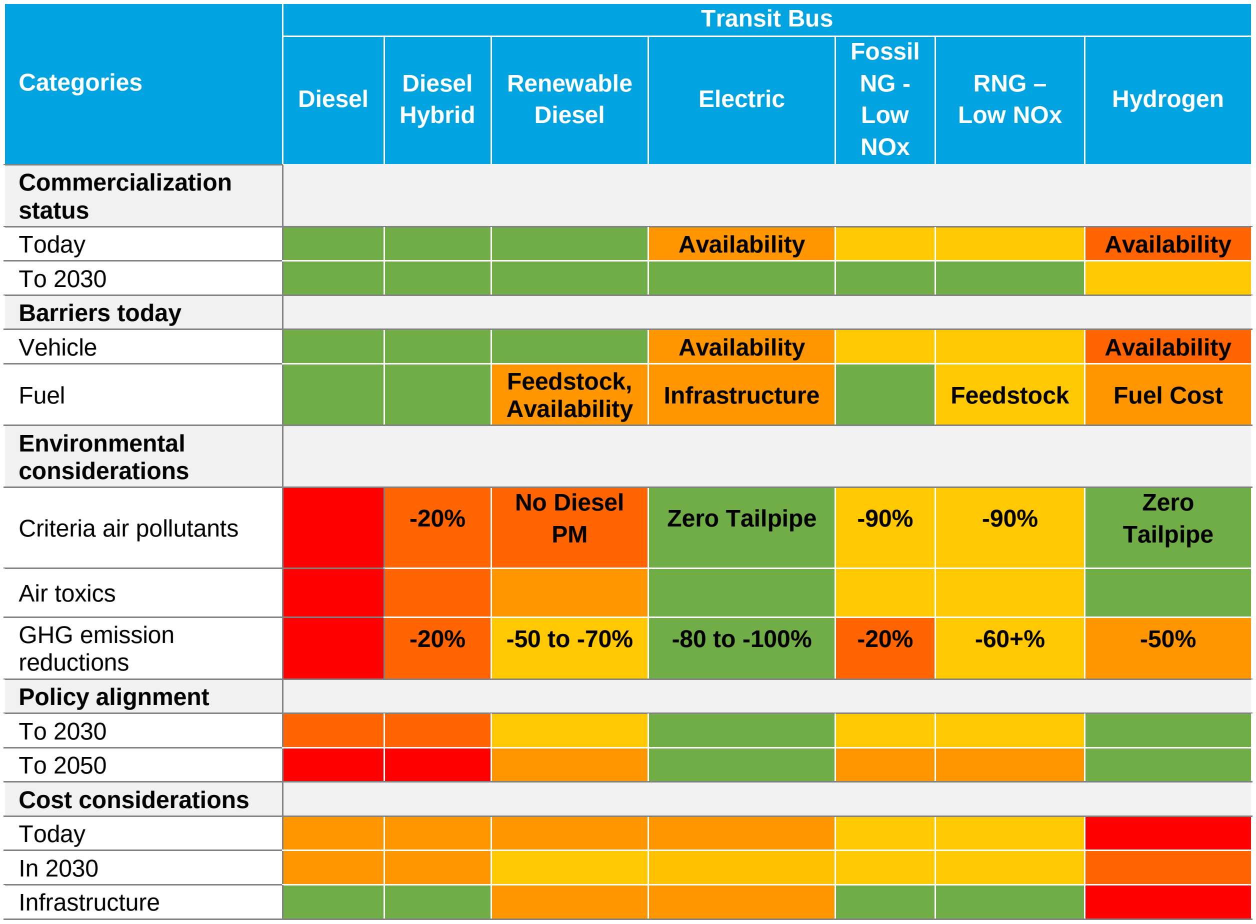
Table II-2. Class 6 Urban Delivery and Class 2b-5 Balanced Scorecard

Categories	Class 6 Urban Delivery and Class 2b-5				
	Diesel	Renewable Diesel	Electric	Fossil NG -Low NOx	RNG – Low NOx
Commercialization status					
Today	🟩	🟩	🟧 **Availability**	🟨	🟨
To 2030	🟩	🟩	🟩	🟩	🟩
Barriers today					
Vehicle	🟩	🟩	🟧 **Availability**	🟨	🟨
Fuel	🟩	🟧 **Feedstock, Availability**	🟧 **Infrastructure**	🟩	🟨 **Feedstock**
Environmental considerations					
Criteria air pollutants	🟥	🟧 **No Diesel PM**	🟩 **Zero Tailpipe**	🟨 **-90%**	🟨 **-90%**
Air toxics	🟥	🟧	🟩	🟨	🟨
GHG emission reductions	🟥	🟨 **-50 to -70%**	🟩 **-80 to -100%**	🟧 **-20%**	🟨 **-60+%**
Policy alignment					
To 2030	🟧	🟨	🟩	🟨	🟨
To 2050	🟥	🟧	🟩	🟧	🟧
Cost considerations					
Today	🟧	🟧	🟧	🟨	🟨
In 2030	🟧	🟨	🟩	🟨	🟨
Infrastructure	🟩	🟧	🟨	🟩	🟩

Compared to the Class 8 technologies presented in the Balanced Scorecard the main differences for these smaller truck classes are the current availability of electric technologies. There are currently more vehicle platforms available for Class 6 urban delivery and Class 2b-5 categories than Class 8, resulting in the commercialization status and vehicle barriers today being a shade lighter. Also, the charging loads necessary for these vehicle categories are much lower than Class 8 resulting in the infrastructure cost considerations to also be a shade lighter. Finally, these trucks have a more favorable TCO in 2030 compared to the refuse and regional haul trucks resulting in a score of green.

3. Transit Bus

Table II-3. Transit Bus Balanced Scorecard



Categories	Transit Bus						
	Diesel	Diesel Hybrid	Renewable Diesel	Electric	Fossil NG - Low NOx	RNG – Low NOx	Hydrogen
Commercialization status							
Today	🟩	🟩	🟩	🟠 **Availability**	🟨	🟨	🟧 **Availability**
To 2030	🟩	🟩	🟩	🟩	🟩	🟩	🟨
Barriers today							
Vehicle	🟩	🟩	🟩	🟠 **Availability**	🟨	🟨	🟧 **Availability**
Fuel	🟩	🟩	🟠 **Feedstock, Availability**	🟠 **Infrastructure**	🟩	🟨 **Feedstock**	🟠 **Fuel Cost**
Environmental considerations							
Criteria air pollutants	🟥	🟧 **-20%**	🟧 **No Diesel PM**	🟩 **Zero Tailpipe**	🟨 **-90%**	🟨 **-90%**	🟩 **Zero Tailpipe**
Air toxics	🟥	🟧	🟠	🟩	🟨	🟨	🟩
GHG emission reductions	🟥	🟧 **-20%**	🟨 **-50 to -70%**	🟩 **-80 to -100%**	🟧 **-20%**	🟨 **-60+%**	🟠 **-50%**
Policy alignment							
To 2030	🟧	🟧	🟨	🟩	🟨	🟨	🟩
To 2050	🟥	🟥	🟠	🟩	🟠	🟠	🟩
Cost considerations							
Today	🟠	🟠	🟠	🟠	🟨	🟨	🟥
In 2030	🟠	🟠	🟨	🟨	🟨	🟨	🟧
Infrastructure	🟩	🟩	🟠	🟠	🟩	🟩	🟥

Compared to the Class 8 technologies presented in the Balanced Scorecard, the main differences for transit buses are the current availability of electric technologies and cost considerations. There are more manufacturer options available for electric and hydrogen transit buses currently than Class 8 resulting in the commercialization status and vehicle barriers today being a shade lighter for both technologies. Based on the TCO results, electric buses do have a lower TCO currently and in 2030 compared to diesel and natural gas buses, but still have a higher incremental vehicle cost compared to diesel and natural gas in 2030. The shading for cost considerations in 2030 was darkened to light orange compared to class 8 trucks. The exception is the 60 foot electric articulated transit bus which has a more favorable TCO and incremental vehicle cost than the traditional 40 foot electric bus.

4. School Bus

Table II-4. School Bus Balanced Scorecard

Categories	School Bus					
	Diesel	Diesel Hybrid	Renewable Diesel	Electric	Fossil NG -Low NOx	RNG – Low NOx
Commercialization status						
Today	🟩	🟩	🟩	🟧 **Availability**	🟨	🟨
To 2030	🟩	🟩	🟩	🟩	🟩	🟩
Barriers today						
Vehicle	🟩	🟩	🟩	🟧 **Availability**	🟨	🟨
Fuel	🟩	🟩	🔶 **Feedstock, Availability**	🔶 **Infrastructure**	🟩	🟨 **Feedstock**
Environmental considerations						
Criteria air pollutants	🟥	🟧 **-20%**	🟧 **No Diesel PM**	🟩 **Zero Tailpipe**	🟨 **-90%**	🟨 **-90%**
Air toxics	🟥	🟧	🔶	🟩	🟨	🟨
GHG emission reductions	🟥	🟧 **-20%**	🟨 **-50 to -70%**	🟩 **-80 to -100%**	🟧 **-20%**	🟨 **-60+%**
Policy alignment						
To 2030	🟧	🟧	🟨	🟩	🟨	🟨
To 2050	🟥	🟥	🔶	🟩	🔶	🔶
Cost considerations						
Today	🟨	🔶	🟨	🔶	🔶	🔶
In 2030	🟨	🔶	🟨	🔶	🔶	🔶
Infrastructure	🟩	🟩	🔶	🔶	🟩	🟩

Compared to the Class 8 technologies presented in the Balanced Scorecard, the main difference for school buses are the cost considerations with higher relative capital costs and TCO analysis results compared to diesel and natural gas. Diesel hybrid, electric, and natural gas are consistently a shade darker than diesel due to their consistent higher TCO analysis results compared to diesel for today and 2030.