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CONSULTANT REPORT

Benefits Associated with Projects and Technologies Supported by the Clean Transportation Program: 2023 Analysis

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PREFACE

Assembly Bill 118 (Núñez, Chapter 750, Statutes of 2007) created the Clean Transportation Program. The statute authorizes the California Energy Commission (CEC) to develop and deploy alternative and renewable fuels and advanced transportation technologies to help attain the state's climate change policies. Assembly Bill 8 (Perea, Chapter 401, Statutes of 2013) reauthorizes the Clean Transportation Program through January 1, 2024, and specifies that the CEC allocate up to $20 million per year (or up to 20 percent of each fiscal year's funds) in funding for hydrogen station development until at least 100 stations are operational.

The Clean Transportation Program has an annual budget of about $100 million and provides financial support for projects that:

- Reduce California's use and dependence on petroleum transportation fuels and increase the use of alternative and renewable fuels and advanced vehicle technologies.
- Produce sustainable alternative and renewable low-carbon fuels in California.
- Expand alternative fueling infrastructure and fueling stations.
- Improve the efficiency, performance, and market viability of alternative light-, medium-, and heavy-duty vehicle technologies.
- Expand the alternative fueling infrastructure available to existing fleets, public transit, and transportation corridors.
- Establish workforce-training programs and conduct public outreach on the benefits of alternative transportation fuels and vehicle technologies.

ABSTRACT

The California Energy Commission's (CEC's) Clean Transportation Program (CTP) supports a wide range of alternative, low-carbon fuel and vehicle projects. This report improves upon the 2021 *Analysis of Benefits Associated With Projects and Technologies Supported by the Clean Transportation Program*, which focused on two components of benefit calculation: expected benefits and market transformation benefits. The "expected benefits" are defined as benefits that accrue because of the direct displacement of petroleum-based fuels or vehicle technologies. The "market transformation benefits" accrue because of CTP funding shifting the underlying market dynamics and accelerating the adoption of alternative fuel vehicles. This report documents the updated methods used in the benefits analysis in the 2021 benefits report. Data collected from CTP projects funded from 2013 to the third quarter of 2023 are used to estimate the benefits between 2013 and 2035. In that time window, the CTP projects analyzed in this report, which reflect $1.04 billion in CEC funding, are estimated to result on average in 64 million gallons per year of petroleum reduction and 460,000 metric tons per year of carbon dioxide equivalent greenhouse gas (GHG) reduction in terms of expected benefits. Market transformation benefits are additive to the expected benefits and are estimated with high and low ranges for the 963 relevant projects evaluated. Conversely, between 2013 and 2035 the market transformation benefits' petroleum reductions are on average estimated as ranging from 4 million to 11 million gasoline gallon equivalents per year, and GHG reductions from 74,000 to 238,000 metric tons of carbon dioxide equivalent per year.

Keywords: California Energy Commission, National Renewable Energy Laboratory, alternative fuels, advanced vehicles, greenhouse gas emissions, criteria air pollutant emissions

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EXECUTIVE SUMMARY

This report updates and expands upon the 2021 *Analysis of Benefits Associated With Projects and Technologies Supported by the Clean Transportation Program* developed by the California Energy Commission (CEC) and the National Renewable Energy Laboratory. The project team used the updated methodology documented in this report to assess the Clean Transportation Program (CTP) benefits. Consistent with the 2021 benefits report, this report focuses on benefits from three categories: expected benefits, market transformation benefits, and economic impact benefits. The expected benefits are defined as benefits that accrue due to the direct displacement of petroleum-based fuels or vehicle technologies; market transformation benefits accrue due to CTP funding shifting the underlying market dynamics and accelerating the adoption of alternative fuel vehicles; and finally, economic impact benefits are positive influences from CTP funding onto California's economy. In total, CTP investment has totaled $1.19 billion since 2013. CEC staff provided sufficient data to evaluate $1.04 billion (88.1 percent) of CTP investments. The benefits estimated in this report consider only the benefits associated directly with the project objectives but do not account for all potential benefits from the investments, such as raising general consumer awareness and enhancing policy development, which are difficult to measure and outside the scope of this analysis.

The expected benefits represent estimates of outcomes attributable to projects that are directly supported by CTP funding. These benefits are based on the estimated displacement of petroleum-derived fuel energy for the vehicles, fuels, or infrastructure supported by each project. To estimate greenhouse gas (GHG) benefits, life cycle carbon intensities are used to determine the GHG emissions associated with each unit of energy. Life cycle carbon intensities capture the emissions associated with each stage of the production and use of a fuel. Estimates of criteria air pollutant emissions reductions are based on baseline petroleum pollution emissions against the reduced pollutant profile of an alternative fuel. For example, hydrogen fuel used in light-duty fuel cell electric vehicles (FCEVs) has no nitrogen oxide (NO_x) or tailpipe particulate matter ($PM_{2.5}$) emissions compared to the internal combustion engine vehicle it displaces. Table ES-1 provides the estimated petroleum displacement in 2020, 2025, 2030, and 2035 by project class and subclass. The amount of petroleum displaced rises steadily through 2030 as more projects come online, utilization of fueling infrastructure increases, and more alternative fuel is produced. Petroleum displacement then falls through 2035 as more projects reach the end of their assumed lifespan.

Table ES-1: Expected Benefits – Petroleum Displacement by Project Class and Subclass

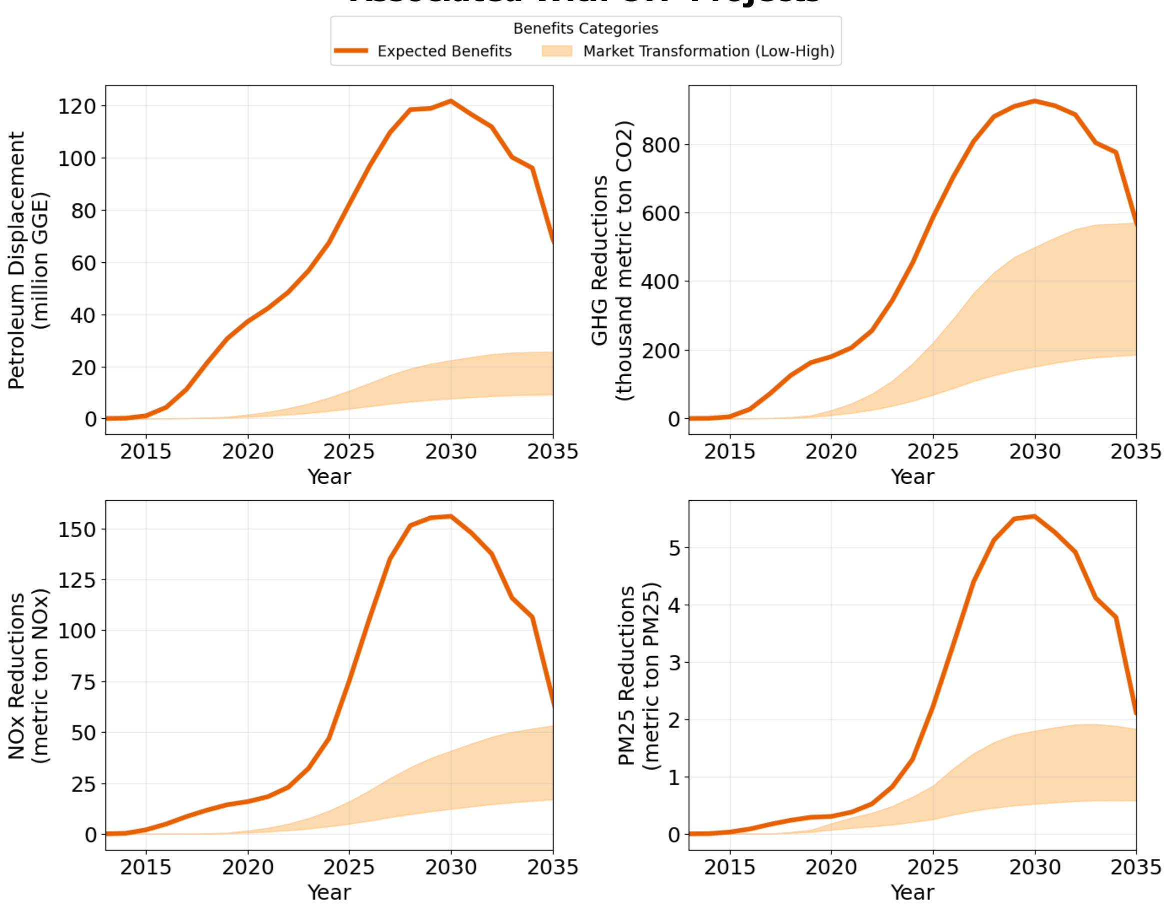
Project Class	Project Subclass	Petroleum Displaced (million gallons of gasoline equivalent)			
		2020	**2025**	**2030**	**2035**
Fuel Production	Biomethane	0.11	5.44	5.84	5.84
Fuel Production	Diesel Substitutes	11.18	18.08	18.08	18.08
Fuel Production	Gasoline Substitutes	7.21	7.47	7.47	7.47

Project Class	Project Subclass	Petroleum Displaced (million gallons of gasoline equivalent)			
		2020	**2025**	**2030**	**2035**
Fueling Infrastructure	E85 Ethanol	2.4	2.5	0	0
Fueling Infrastructure	Electric Chargers	2.18	24.96	68.72	25.69
Fueling Infrastructure	Electric Chargers – Medium- and Heavy-Duty Vehicles	0.05	0.98	3.47	3.06
Fueling Infrastructure	Hydrogen	1.51	6.42	13.17	7.3
Fueling Infrastructure	Hydrogen – Medium- and Heavy-Duty Vehicles	0	0.19	1.43	1.53
Fueling Infrastructure	Natural and Renewable Gas	10.16	10.76	0.15	0
Vehicles	Clean Vehicle Rebate Project and Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project Support	1.36	1.48	0	0
Vehicles	Demonstration	0.43	1.12	0.58	0
Vehicles	Light-Duty Battery-Electric Vehicles (BEVs) and Plug-In Hybrid Electric Vehicles	0	0.04	0.04	0
Vehicles	Natural Gas Commercial Trucks	0.58	2.76	2.86	0
Total	*Total*	*37.18*	*82.21*	*121.8*	*68.97*

Contrary to expected benefits, market transformation benefits attempt to model the influence of CTP-funded projects to shift California's markets toward alternative fuel vehicles. For example, the continuing market expansion of plug-in electric vehicles (PEVs) might be partially supported by CTP investments into electric charging infrastructure, as charging availability is a leading consumer concern for vehicle adoption, and additional electric chargers may affect consumers' decisions to purchase a PEV. Because market transformation benefits are highly sensitive to assumptions on both California's vehicle market and consumer choices—both of which are difficult to model—the benefits are presented as a range of potential outcomes based on the assumptions made. Importantly, for expected benefits and market transformation benefits, the estimated benefits are associated with a project that the CTP funds at any level, without regard to other sources of funding. For example, California's Low Carbon Fuel Standard (LCFS) and the U.S. Renewable Fuel Standard program provide substantial incentives aimed at increasing the use of alternative fuels; however, this report does not distinguish the CTP contribution toward those project benefits from other regulations and incentives. Rather, the report captures the expected and market transformation benefits for each project as a whole.

Figure ES-1 summarizes the expected and market transformation benefits associated with CTP-funded projects analyzed in this report. While expected benefits are estimated under only one set of assumptions and therefore are presented as lines on the figure, due to the greater uncertainty in the input parameters necessary to estimate market transformation benefits, these are presented as a range of results, defined by low and high scenarios. CTP-funded projects are estimated to provide significant environmental benefits. GHG, NO_x, and $PM_{2.5}$ emissions reductions for projects funded through 2023 all rise significantly from 2013 through 2030 before falling through 2035. Nearly 1 million metric tons of carbon dioxide equivalent (CO_2e) are reduced annually by 2030, 350 percent above 2021 levels. The cumulative emissions reductions associated with CTP-funded projects from 2021 to 2030 account for nearly 5 percent of transportation GHGs emitted in California in 2021. Market transformations resulting from CTP-funded projects could reduce GHG emissions by 165,260–522,190 metric tons of CO_2e annually in addition to the expected benefits by 2030. Air quality benefits are only estimated for fueling infrastructure and vehicle projects. CTP-funded projects are estimated to reduce NO_x emissions by 156 metric tons per year in 2030 and $PM_{2.5}$ emissions by 5.5 metric tons per year in 2030. Market transformations could provide up to 2 and 40 additional metric tons of $PM_{2.5}$ and NO_x emissions reductions, respectively, per year.

Figure ES-1: Summary of Expected Benefits and Market Transformation Benefits Associated With CTP Projects



Source: National Renewable Energy Laboratory

In the expected benefits analysis, projects are assigned to census tracts, and results are also presented in terms of the share of benefits realized in disadvantaged or low-income communities. This analysis can only be performed on a subset of projects in which geospatial attributes are available. In all years, across all four benefits categories, and of the projects with geospatial attributes, the majority of expected benefits occur in disadvantaged or low-income communities. A key outcome of the expected benefits analysis is that 78 percent of NO_x and $PM_{2.5}$ emissions reductions from projects with geospatial attributes are attributable to disadvantaged or low-income communities by 2030.

Finally, the economic impacts of CTP-funded projects in California are estimated using the IMpact Analysis for PLANning (IMPLAN) platform. This analysis uses CTP project budget information to allocate expenditures in local goods and services for each year. The $1.4 billion (in 2022 dollars) of CTP-funded projects in California support around 590 wage and salary jobs per year across the state. Most occupations are expected to be in professional services, construction, and wholesale/retail sectors. One-third of the jobs created are in service-related occupations; 20 percent in construction, installation, and transportation occupations; and 4 percent in manufacturing occupations. CEC investments mostly increase job opportunities for low-skilled workers with less than a year of prior work experience.

CHAPTER 1: Introduction

As of 2023, the transportation sector is the largest contributor of carbon dioxide emissions and is projected to increase its share of total U.S. emissions.[1] Shifting the transportation system from a reliance on petroleum-based fuels toward low-carbon alternatives takes time and considerable financial investments. California leads the United States in moving its transportation systems toward sustainable alternatives through state and federal policies aimed at improving energy security, addressing environmental considerations such as GHG emissions, and achieving economic goals such as workforce training and rural development.

The CEC's strategic goal is to catalyze private market innovation and development through CTP investment support in a wide array of emerging technologies. CEC investments are small relative to the overall investment in the energy sector, but they are a critical component in areas such as electric, fuel cell, and natural gas vehicles; low-carbon fuel production technologies; and zero-emission vehicle (ZEV) and alternative fuel retail infrastructure. Given the diversity of projects supported by the CTP, the availability of data for estimating benefits varies significantly.

Market adoption of alternative and renewable fuels and vehicles remains a challenge for well-developed economies due to a variety of market challenges, including vehicle costs, fixed costs of building infrastructure to support the vehicles, and overall uncertainty of the future transportation market. Specifically, the transportation sector continues to be the most difficult sector to shift toward renewable sources such as solar and wind, yet significant progress has been made since this analysis was last conducted in 2021. As of December 2023, California has over 83,597 public and shared Level 1 and Level 2 (L2) chargers and 10,258 direct-current fast chargers (DCFCs) supporting 1,111,028 PEVs (BEVs and plug-in hybrid electric vehicles [PHEVs])[2] and 66 hydrogen refueling stations (HRSs) supporting over 11,897 FCEVs.[3] These numbers are in contrast to the 76,172 charge points supporting 980,225 PEVs and 52 HRSs supporting 7,993 FCEVs in 2021.[4]

This strong market growth results in direct environmental benefits, including GHG emissions reductions, as well as indirect benefits including public health improvements and increased energy security. Such strong growth in clean transportation technologies can be linked to

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[1] U.S. Energy Information Administration. 2023. "Annual Energy Outlook 2023 With Projections to 2050." Available at https://www.eia.gov/outlooks/aeo/.

[2] California Energy Commission. 2023. "Zero Emission Vehicle and Infrastructure Statistics." Data last updated Dec. 5th, 2023. Available at https://www.energy.ca.gov/zevstats.

[3] California Air Resources Board. 2021. *2021* Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development. Sacramento, California: California Air Resources Board. Available at https://ww2.arb.ca.gov/sites/default/files/2021-09/2021_AB-8_FINAL.pdf.

[4] U.S. Department of Energy. 2021. "Alternative Fuels Data Center." Accessed November 3rd, 2021. Available at https://www.afdc.energy.gov.

direct government financial support, as well as reduced uncertainty in future market conditions that stimulates additional private investment. The CTP has continued to make strategic investments in a broad portfolio of projects that support the developing alternative transportation technology markets.

This 2023 benefits report updates the input data, calculation methodologies, and resulting outputs from the CEC's 2021 *Analysis of Benefits Associated With Projects and Technologies Supported by the Clean Transportation Program*.[5] Many of the methods in the 2021 benefits report are updated or adapted from the original 2014 benefits report.[6]

As in previous iterations of this analysis, the benefit estimation methods used in this work might not be sufficient to determine the comparative effectiveness of different CTP investment categories. Effectiveness metric assessments are limited by the completeness and consistency of the cost-share information provided for each project (or lack thereof), as well as the uncertainty in future market outcomes and time scales. For a more detailed discussion on the limitations in determining effectiveness metrics to assess individual investments, please refer to Section 1.2 of the 2014 benefits report.[7]

Projects Summary

The benefits in this analysis are estimated for projects completed in the last decade—since 2013. In this time window, CTP funding has accrued to $1.19 billion, allocated to 1,265 projects. However, not all projects from this grand total could be included in this analysis, as some of the projects had insufficient information available or a methodology to their benefits could not be devised. Consequently, benefits reported in this article encompass 976 projects, for a total of $1.04 billion in funding.

Figure 1 presents a breakdown of the total funding included in this analysis in three main project classes: Fuel Production, Fueling Infrastructure, and Vehicles. The fuel production class includes projects devoted to the production of renewable fuels such as biomethane, gasoline and diesel substitute, and renewable hydrogen. Conversely, the fueling infrastructure class features projects aimed at increasing the availability of infrastructure to fuel alternative vehicles, such as electric vehicles (EVs) and FCEVs, by supporting its installation. Finally, the vehicles class represents support to projects ranging from the direct deployment of vehicles to improvements in vehicle manufacturing processes and the provision of rebates toward the purchase of alternative fuel vehicles. In addition to being defined by classes, projects are also categorized into subclasses, providing additional detail on how analyzed CTP funding is allocated. The number of projects and funding allocated to the different subclasses are summarized in Table 1.

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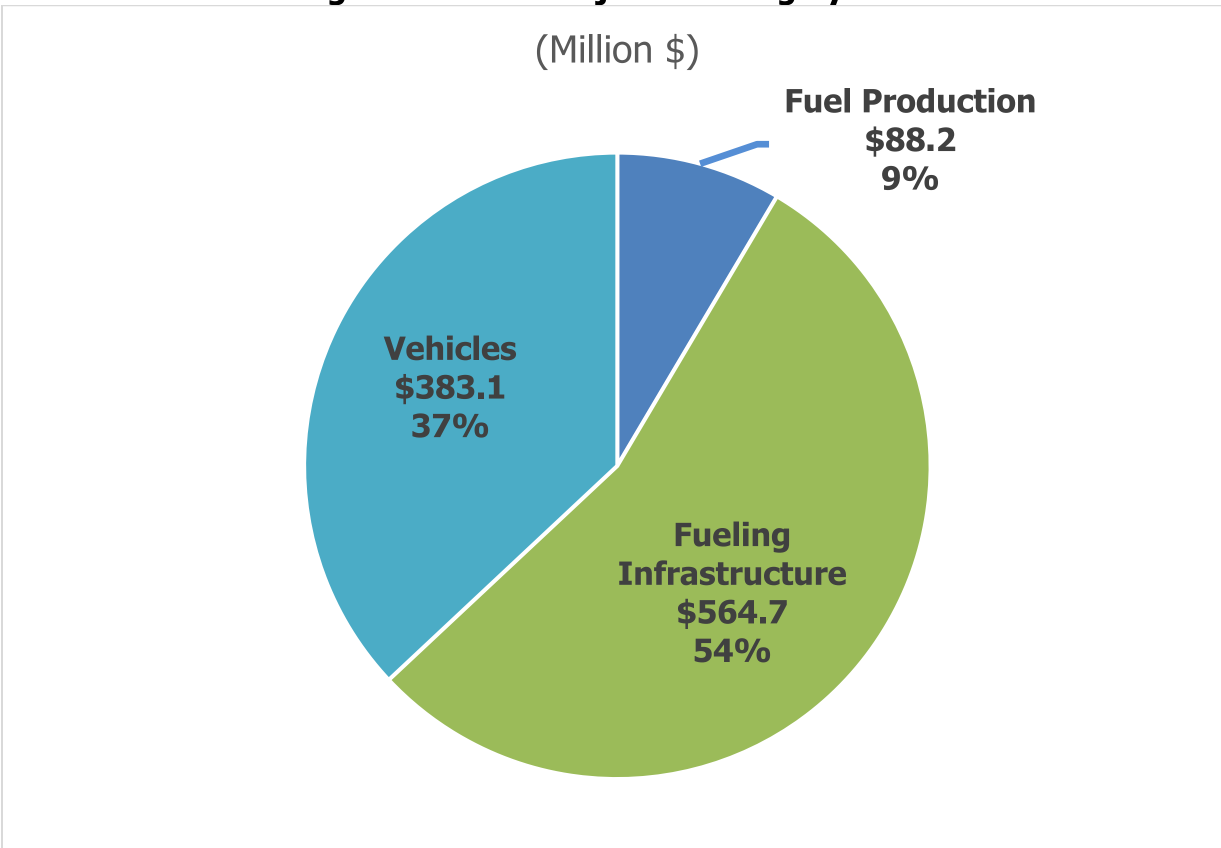
[5] Neuman, C., M. Gilleran, C. Hunter, R. Desai, and A. F. T. Avelino (NREL). 2021. *Analysis of Benefits Associated With Projects and Technologies Supported by the Clean Transportation Program*. California Energy Commission. Publication Number: CEC-600-2021-039.

[6] Melaina, M., E. Warner, Y. Sun, E. Newes, and A. Ragatz (NREL). 2014. *Program Benefits Guidance: Analysis of Benefits Associated with Projects and Technologies Supported by the Alternative and Renewable Fuel and Vehicle Technology Program*. California Energy Commission. Publication Number: CEC-600-2014-005-D.

[7] Ibid.

Figure 1: Total Project Funding by Class



Source: National Renewable Energy Laboratory (NREL)

Table 1: Projects and Funding Included in This Analysis, Presented by Project Class

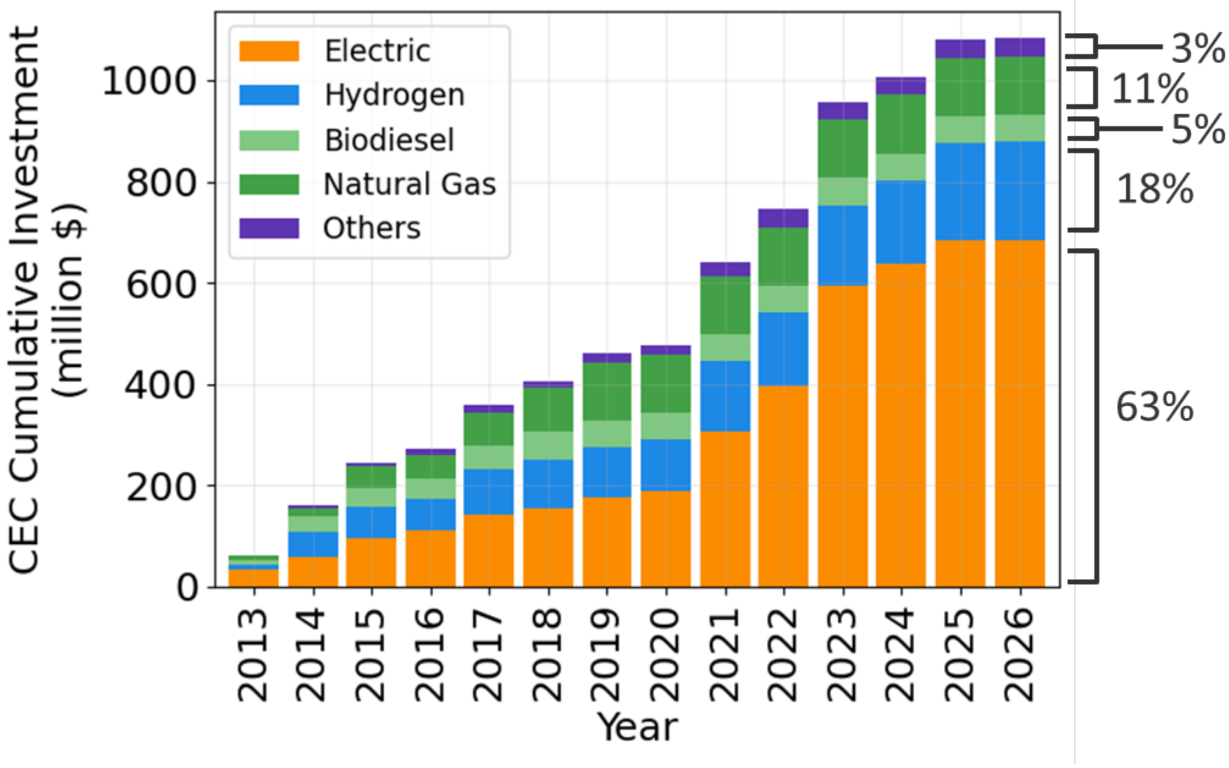
Project Class	Project Type	Number of Projects Analyzed	CTP Funding Analyzed ($ millions)
Fuel Production	Biomethane Production	12	$35.9
	Gasoline Substitutes Production	5	$10.7
	Diesel Substitutes Production	10	$41.5
Fueling Infrastructure	EV Charging – Light Duty (LD)	621	$288.6
	EV Charging – Medium and Heavy Duty (MD/HD)	89	$72.2
	HRSs – LD	89	$135.9
	HRSs – MD/HD	4	$25.5
	E85 Fueling Stations	19	$1.4

Project Class	Project Type	Number of Projects Analyzed	CTP Funding Analyzed ($ millions)
	Natural Gas Fueling Stations	41	$14.8
	Manufacturing (Infrastructure)	8	$26.4
Vehicles	Natural Gas Commercial Trucks	13	$51.3
	LD BEVs and PHEVs	4	$2.8
	Clean Vehicle Rebate Project (CVRP) and Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP) Support	2	$22.5
	MD/HD Truck Demonstration	33	$79.8
	Manufacturing (Vehicles)	26	$226.7
Total		**976**	**$1,036**

Source: NREL

Finally, to further contextualize the funding analyzed in this report, Figure 2 presents cumulative CTP allocated funding for each year between 2013 and 2026 according to different types of fuel. The figure shows that while in the earlier years of the program there was a more equal distribution of funds across fuel types, since 2020 it appears that CTP funding has increasingly flowed to projects related to EVs. When all projects for which funding from the CTP has been allocated are active in 2026, EV-related projects are expected to constitute 63 percent of the total funding allocated, followed by hydrogen with 18 percent.

Figure 2: Cumulative CTP Funding by Fuel Type Since 2013



Source: NREL

The remainder of this report is structured as follows. Chapter 2 describes the methodology used to estimate the expected benefits associated with CTP-funded projects and presents expected benefits results, Chapter 3 describes the methodology for and presents results of the market transformation analysis, Chapter 4 presents the methodology and the results of the economic impacts analysis, and finally Chapter 5 presents the conclusions.

CHAPTER 2: Expected Benefits

This chapter focuses on a subset of total CTP projects for which sufficient project-level data are available to estimate expected benefits using the methodology outlined in the subsequent section. Moreover, despite the fact that the CTP has been active since 2009, the results presented in this analysis only encompass projects funded between January 1, 2013, and June 29, 2023. Within this window of time, projects for which there is sufficient information to be included in the analysis amount to $1.04 billion in funding, 88.1 percent of total CTP funding in the same period.

Methodology

A workflow and multiple models are constructed to estimate expected benefits in the form of reductions in petroleum consumption, GHG emissions, NO_x emissions, and $PM_{2.5}$ emissions. The reported results are not directly comparable to the estimated expected benefits presented in the 2021 benefits report due to updated input parameters and project data, changes to key assumptions, and methodological improvements.

Consistent with the 2021 benefits report, the expected benefits model estimates the reduction of petroleum fuel consumption and emissions due to consumption of alternative fuels or adoption of alternative vehicles. Indirect effects of the projects, including land-use changes or potential petroleum price shifts due to the use of biofuels, are generally beyond the scope of this assessment. However, consistent with the 2021 benefits report, the one exception is that life cycle GHG emissions for select biofuels, including GHG emissions from indirect land-use change, are estimated to reflect the scope of the California Air Resources Board's (CARB's) LCFS.[8]

Expected benefits for each project are estimated, and results are aggregated over relevant project categories. The first step of the analysis is estimating reductions in petroleum fuel consumption. The next step is estimating GHG emissions reductions and, in some cases, reductions in criteria air pollutant emissions. Estimates are based on input data from CEC staff, the CEC's Transportation Energy Demand Forecast, life cycle assessment models (CA-GREET),[9] and vehicle stock models (EMission FACtor [EMFAC]).[10]

The target year for this report is 2035, and annual benefits are estimated and presented from 2013 to 2035. In some figures and tables, results are summarized for the years 2020, 2025, 2030, and 2035 for brevity. As in the 2021 benefits report, the expected benefits are calculated for only one scenario, reflecting assumptions used in the previous report. In contrast, the market transformation calculations in Chapter 4 include multiple scenarios to provide a potential range of solutions depending on the selected input assumptions.

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[8] CARB. 2006. "Title 17 Chapter 1 Subchapter 10 Article 4 Subarticle 7 Low Carbon Fuel Standard." California Code of Regulations Final Regulation Order, 128.

[9] CARB. 2023. "LCFS Life Cycle Analysis Model and Documentation." Available at https://ww2.arb.ca.gov/resources/documents/lcfs-life-cycle-analysis-models-and-documentation.

[10] CARB. 2023. "EMFAC." Available at https://arb.ca.gov/emfac/.

As noted in the 2021 benefits report, the focus on one scenario for expected benefits does not imply certainty in the benefits estimates. This report presents expected benefits projections under one specific set of assumptions. There are several sources of uncertainty that affect the outcomes projected in this analysis. For example, there is uncertainty in the pace of ZEV adoption, technological process, federal and state policies affecting clean transportation, and socioeconomic and geopolitical factors, among others. However, considerations of these sources of uncertainty are beyond the scope of this report.

Petroleum Displacement

Petroleum reduction estimates for fuel production projects, fueling infrastructure projects, and vehicles projects are calculated based on different methods. For fuel production projects, the model uses fuel production throughput, included in the information provided by CEC staff, to determine the displacement of petroleum fuels. The throughput values are given either in gasoline gallon equivalents (GGE) or diesel gallon equivalents. The alternative fuel production throughputs are assumed to displace petroleum fuel on a one-to-one basis. The fuel production throughput is multiplied by the project's expected capacity factor to determine the petroleum fuel reductions for each year. To determine the capacity factor—i.e., the percentage of the year the project is effectively operating, hereinafter referred to as "percent year operation"—the model assumes that projects begin operation nine months before the contract end date and take three years to linearly ramp up to full capacity. After the project has ramped up, it is assumed that it will operate at full capacity for the duration of the project life. A percent year operation equal to one reflects full capacity. This assumption is consistent with the 2021 benefits report. It follows that the petroleum reduction (PET_{red}) for fuel production projects are calculated using the following equation:

$$PET_{red} = FP \cdot P_{year}$$

where FP is the fuel throughput and P_{year} is the percent year operation.

Petroleum reductions associated with fueling infrastructure projects can be estimated in one of two ways, depending on whether or not the project is an electric vehicle supply equipment (EVSE) project. For non-EVSE projects, petroleum reductions are based again on the fuel throughput, the percent year operation, and the fuel's energy economy ratio (EER). For LD HRSs, a nameplate station refueling capacity (in kilograms of hydrogen per day) is translated to effective hydrogen throughput using a utilization factor, which is based on the observed utilization of CEC-funded stations in California. Figure A-1 in Appendix A presents more information on how this utilization factor is calculated. For the other non-EVSE fueling infrastructure projects, the throughput values are provided within the CTP project data provided by the CEC, and the yearly percentage operation is calculated as described above based on the project end date and a three-year linear ramp-up to full capacity. The EER associated with alternative vehicles reflects the drivetrain efficiency of the alternative vehicle relative to an internal combustion engine vehicle and can be represented as the ratio fuel economies in terms of delivered energy. If the new vehicle fuel economy data are not available, the EER is assumed constant over time and is taken from Table A-6 in Appendix A.[11]

[11] CARB. 2023. "Low Cabon Fuel Standard." Accessed November 2023. Available at https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard.

The petroleum reductions are then calculated by multiplying the production throughput by the percent year operation and the energy efficiency ratio, EER_{alt}:

$$PET_{red} = EER_{alt} \cdot \mathrm{FP} \cdot P_{year}$$

The petroleum reduction benefits from LD EVSE projects are based on the estimated number of miles enabled by the charger VMT_{alt} (i.e., miles that would not have been driven without the public charger, such as only with home chargers), the fuel economy of the conventional gasoline vehicle replaced FE_{rep}, and the percent year operation:

$$PET_{red} = \frac{VMT_{alt} \cdot P_{year}}{FE_{rep}}$$

The number of additional miles provided by each type of EVSE is based on the EVI-Pro 2 model,[12,13] which uses travel data from the 2012 California Household Travel Survey[14] and the National Household Travel Survey[15] limited to the state of California. EVI-Pro 2 is used to determine the number and type of EVSE charging stations required to support California's EV adoption goals with respect to workplace and residential charging, as well as projected usage of charging stations by location and type. The electricity throughput (average kilowatt-hours per plug per year) is then used to determine the equivalent number of miles electrified (e-miles) by each type of EVSE by dividing the electricity dispensed by the average energy consumption of the expected distribution of EV efficiencies. Table 2 provides the estimated e-miles provided by each connector on an annual basis.

Table 2: Average E-Miles Enabled per Charge Point by Year

Year	L2 Public	L2 Multifamily	L2 Workplace	Public DCFC 50-kW Max Power	Public DCFC 150-kW Max Power
2020	11,421	11,421	17,977	107,224	321,671
2021	11,711	16,105	20,496	120,724	362,172
2022	12,473	21,338	24,175	135,961	407,884
2023	12,784	25,803	26,333	151,198	453,595
2024	13,186	30,305	29,914	166,436	499,307
2025	14,524	36,981	31,379	181,673	545,019
2026	14,527	36,983	32,754	196,910	590,730

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[12] Wood, E., S. Raghavan, C. Rames, J. Eichman, and M. Melaina. 2017. *Regional Charging Infrastructure for Plug-In Electric Vehicles: A Case Study of Massachusetts*. Golden, Colorado: National Renewable Energy Laboratory. NREL/TP-5400-67436. Available at https://www.nrel.gov/docs/fy17osti/67436.pdf.

[13] The EVI-Pro model vintage of 2017 was used when estimating the CTP benefits in 2017. The same coefficients were used in this report, as they were not expected to change significantly from 2017.

[14] NuStats Research Solutions. 2013. "2010-2012 California Household." California Department of Transportation.

[15] Federal Highway Administration. 2019. "2019 National Household Travel Survey." Washington, D.C.: U.S. Department of Transportation. Available at https://nhts.ornl.gov.

Year	L2 Public	L2 Multifamily	L2 Workplace	Public DCFC 50-kW Max Power	Public DCFC 150-kW Max Power
2027	14,257	36,331	35,413	212,147	636,442
2028	14,117	35,990	36,881	227,384	682,153
2029	14,099	35,947	38,028	242,622	727,865
2030	14,525	36,981	38,864	257,859	773,577

Source: NREL

For EVSE projects specifically tailored to MD/HD vehicles, the petroleum reductions depend on the vehicle miles traveled (VMT) by the replaced vehicles (VMT_{rep}), as well as their fuel efficiency (FE_{rep}), number of vehicles supported by the station (N), and percent operation of the station:

$$PET_{red} = \frac{VMT_{rep} \cdot N \cdot P_{year}}{FE_{rep}}$$

Lastly, vehicle projects' petroleum reductions are calculated assuming that new vehicles would replace new conventional vehicles rather than other new alternative fuel vehicles. When the alternative fuel vehicles enter the market (nine months before the contract end date in this model), VMT and fuel economy of the replaced conventional vehicle are used to calculate the petroleum fuel reductions. As the vehicle ages, the VMT and fuel economy depreciate, reducing the petroleum reductions over time until the vehicle is retired. Petroleum reductions for vehicle projects are calculated using the following equation:

$$PET_{red} = \frac{VMT_{rep} \cdot N \cdot P_{year}}{FE_{rep}}$$

Data on the VMT and fuel economy by year and vehicle/fuel type are extracted from the CARB EMFAC model and are presented in Appendix A. For vehicle projects, it is assumed that the model year of the new and conventional fuel (displaced) vehicles is the year associated with the project starting, nine months before the contract end date. Additionally, to use the EMFAC data on fuel economy and VMT, each of the vehicle projects must be matched to a vehicle type in the database.[16] Approximate matches based on vehicle weight and occupation might need to be made to use the EMFAC data, as the EMFAC model does not contain data for all vehicle, fuel, model year, and calendar year combinations needed to evaluate all the CTP projects. For example, a project that provides program funds to expand electric motorcycle production would be omitted since the EMFAC model does not include motorcycle data. Thus, the 2011 fuel economy and annual VMT of gasoline motorcycles was extracted from the U.S. Department of Energy's Alternative Fuels Data Center and used for this analysis.[17] The 2011 values are then scaled to match the percentage changes in fuel economy and VMT observed

[16] For a detailed description of the vehicle categories, visit Appendix 4 of the *EMFAC2021 Volume I – User's Guide*, available at https://ww2.arb.ca.gov/sites/default/files/2021-01/EMFAC202x_Users_Guide_01112021_final.pdf.

[17] U.S. Department of Energy Office of Energy Efficiency & Renewable Energy. 2015. "Maps and Data - Average Annual Vehicle Miles Traveled by Major Vehicle Category." Available at https://www.afdc.energy.gov/data/10309.

for gasoline LD vehicles, as reported by the EMFAC model. Similarly, fuel economy and VMT for electric motorcycles are estimated by scaling the corresponding gasoline motorcycle value by the ratio of fuel economy and VMT of gasoline and electric LD vehicles.

GHG Emissions Reductions

In this report, GHG emissions reductions are a key benefit of CTP-funded projects. GHG emissions reductions are estimated for each project by multiplying the displaced petroleum fuel energy by an associated GHG emissions reduction factor.

The GHG emissions reductions factors capture the reduction in GHG emissions from displacing 1 megajoule of the replaced fuel energy with an alternative fuel. GHG emissions reductions (in metric tons) are determined using the following equation:

$$GHG_{red} = PET_{red} \cdot ED_{rep} \cdot k_{GHG}$$

where PET_{red} is the petroleum displaced, ED_{rep} is the energy density of gasoline, and k_{GHG} is the GHG emissions reduction factor in grams CO_2e per unit energy. The GHG emissions reduction factor is equal to the difference between the life cycle carbon intensity (CI) of the replaced fuel (gasoline or diesel, depending on the alternative fuel or vehicle type) and the life cycle CI of the alternative fuel, respectively CI_{rep} and CI_{alt}, adjusted by the EER of the applicable vehicle type EER_{alt}. In each year, GHG emissions reductions factors are estimated using the following equation:

$$k_{GHG} = CI_{rep} - \frac{CI_{alt}}{EER_{alt}}$$

In this analysis, CI_{rep} is equal to the LCFS CI target for the replaced fuel in each year. That is, every megajoule of diesel energy displaced has a CI equal to the LCFS diesel target, and every megajoule of gasoline displaced has a CI equal to the LCFS gasoline target. This assumption is made to capture the fact that the CIs of gasoline and diesel fuels are declining to comply with the LCFS. The gasoline and diesel targets are shown in Table A-4.

The CI of the alternative fuel (CI_{alt}) is estimated differently for the three project classes. For nearly all fuel production projects included in this analysis, the information provided by CEC staff includes a CI for the fuel pathway associated with the project. These values are used to calculate the project-specific GHG emissions reduction factors. For the fuel production projects without a specified CI, the volume-weighted average CI of the applicable fuel (or specific fuel–feedstock combination when the feedstock is specified) observed in 2022 is assigned.[18] For the other CTP project classes (i.e., vehicles and fueling infrastructure), the corresponding fuel is assigned a CI based on the volume-weighted average CI of the applicable fuel (or specific fuel–feedstock combination when the feedstock is specified) observed in 2022.[19] As in the 2021 benefits report, the CI of electricity as a transportation fuel is assumed to be the California marginal grid CI.[20]

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[18] CARB. 2023. "Low Carbon Fuel Standard Reporting Tool Quarterly Summaries." Available at https://ww2.arb.ca.gov/sites/default/files/2023-10/quarterlysummary_Q22023.xlsx.

[19] Ibid.

[20] CARB. 2023. "LCFS Pathway Certified Carbon Intensities." Available at https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/fuelpathways/current-pathways_all.xlsx.

The EER reflects the drivetrain efficiency of an alternative vehicle relative to an internal combustion engine vehicle. In cases where the drivetrain of the alternative vehicle is different than an internal combustion engine vehicle, the EER is different than one. The EERs used in this analysis for each fuel and vehicle combination are shown in Table A-6. Because there are different EERs associated with light- and heavy-duty vehicles, the GHG emissions reduction factor differs across vehicle types even when the fuel feedstock is the same.

Criteria Air Pollutant Emissions Reductions

Reductions in criteria air pollutant emissions are another key benefit analyzed in this report. The pollutants considered in this analysis include NO_x and $PM_{2.5}$. Different methods are used for calculating criteria air pollutant emissions reductions across projects classes. For vehicle projects and MD/HD electric infrastructure projects, NO_x emissions reductions are calculated as follows:

$$NOX_{red} = N \cdot VMT_{rep} \cdot (NOX_{rep} - NOX_{alt}) \cdot P_{year}$$

where N is the number of alternative vehicles, VMT_{rep} is the VMT for the replaced vehicle, NOX_{rep} is the NO_x emissions factor for the replaced vehicle, NOX_{alt} is the NO_x emissions factor for the alternative vehicle, and P_{year} is the percent operation. Similarly, $PM_{2.5}$ emissions reductions (grams $PM_{2.5}$ per year) are calculated as:

$$PM_{red} = N \cdot VMT_{rep} \cdot (PM_{rep} - PM_{alt}) \cdot P_{year}$$

where PM_{rep} is the $PM_{2.5}$ emissions factor for the replaced vehicle and PM_{alt} is the $PM_{2.5}$ emissions factor for the alternative vehicle.

The NO_x emissions reductions for non-electric fueling infrastructure projects are calculated as:

$$NOX_{red} = FP \cdot FE_{rep} \cdot P_{year} \cdot (NOX_{rep} - NOX_{alt})$$

where FP is the fuel throughput and FE_{rep} is the fuel economy of the replaced vehicle. The $PM_{2.5}$ emissions reductions for these same projects are calculated similarly but using the difference in the $PM_{2.5}$ reduction factors:

$$PM_{red} = FP \cdot FE_{rep} \cdot P_{year} \cdot \left(PM_{rep} - PM_{alt}\right)$$

The reductions for EVSE are based on the reduction factors of gasoline LD automobiles, the number of e-miles, and the percent year operation:

$$NOX_{red} = VMT_{alt} \cdot \left(NOX_{rep} - NOX_{alt}\right) \cdot P_{year}$$

$$PM_{red} = VMT_{alt} \cdot (PM_{rep} - PM_{alt}) \cdot P_{year}$$

Consistent with the 2021 benefits report, reductions in criteria air pollutants are not calculated for fuel production projects, as these are not associated with specific types of vehicles.

Results

In this section, we present results from the expected benefits analysis. Table 3 summarizes the estimated annual petroleum reductions for each project class and subclass in 2020, 2025, 2030, and 2035. The projects analyzed in this report are estimated to displace a peak of 122 million GGE annually by 2030, falling to 69 million GGE per year in 2035, the end of the modeling horizon. Petroleum displacement (and other benefits) from fueling infrastructure and vehicle projects generally decrease from 2030 to 2035 because the assumed life span of those projects are 10 years, and many of the projects in those categories come online between 2021 and 2025. The expected benefits associated with fuel production projects do not tend to experience the same decline from 2030 to 2035 because the assumed life span of fuel production projects is 20 years.

Table 3: Petroleum Displacement by Project Class and Subclass

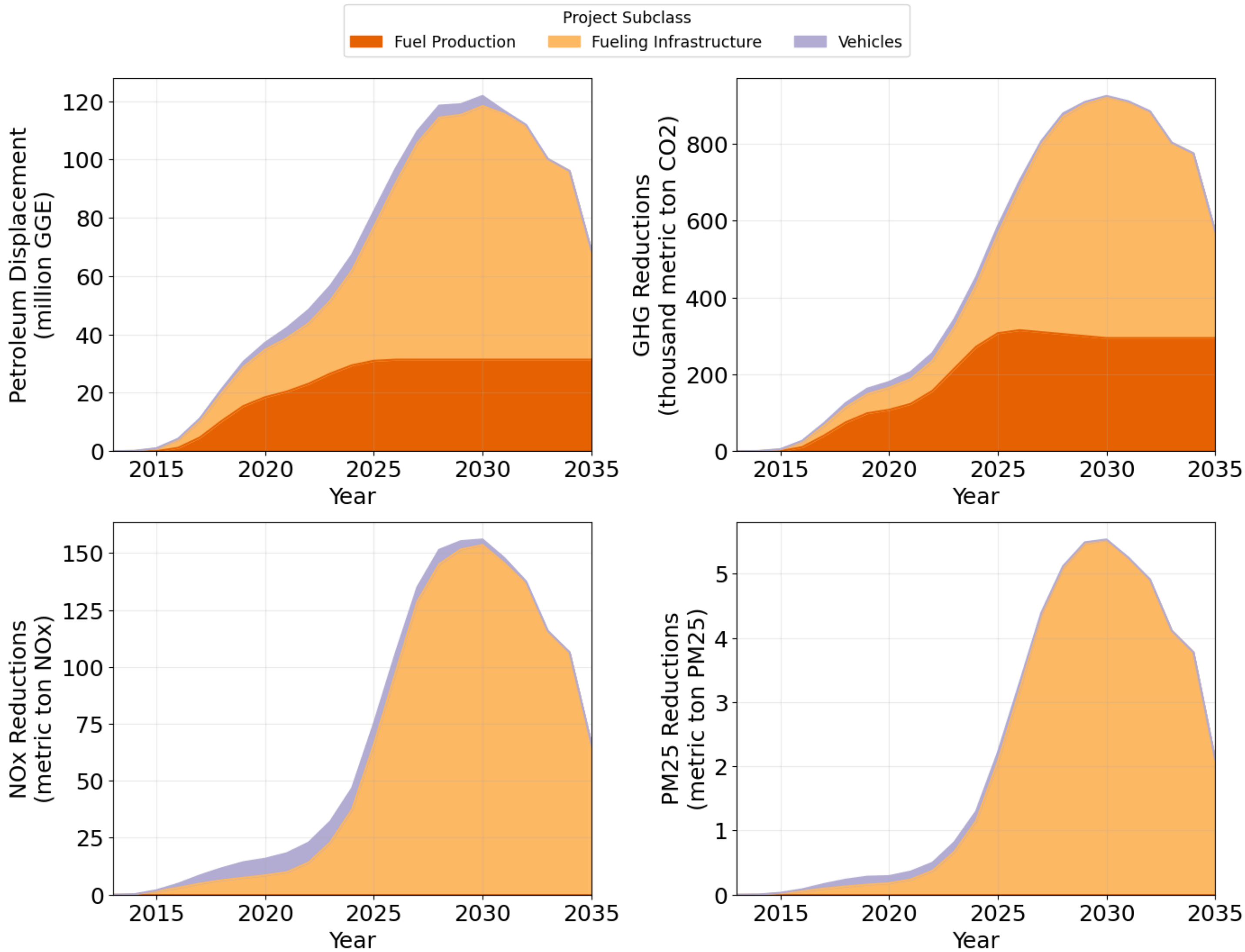
Project Class	Project Subclass	Petroleum Displaced (million GGE)			
		2020	2025	2030	2035
Fuel Production	Biomethane	0.11	5.44	5.84	5.84
Fuel Production	Diesel Substitutes	11.18	18.08	18.08	18.08
Fuel Production	Gasoline Substitutes	7.21	7.47	7.47	7.47
Fueling Infrastructure	E85 Ethanol	2.4	2.5	0	0
Fueling Infrastructure	Electric Chargers	2.18	24.96	68.72	25.69
Fueling Infrastructure	Electric Chargers – MD/HD Vehicles	0.05	0.98	3.47	3.06
Fueling Infrastructure	Hydrogen	1.51	6.42	13.17	7.3
Fueling Infrastructure	Hydrogen – MD/HD Vehicles	0	0.19	1.43	1.53
Fueling Infrastructure	Natural and Renewable Gas	10.16	10.76	0.15	0
Vehicles	CVRP and HVIP Support	1.36	1.48	0	0
Vehicles	Demonstration	0.43	1.12	0.58	0
Vehicles	LD BEVs and PHEVs	0	0.04	0.04	0
Vehicles	Natural Gas Commercial Trucks	0.58	2.76	2.86	0
Total	Total	37.18	82.21	121.8	68.97

Source: NREL

Figure 3 summarizes the estimated petroleum displacement, GHG emissions reductions, and criteria air pollutant emissions reductions for each of the three major project classes. Nearly 1 million metric tons of CO_2e are reduced annually by 2030, 350 percent above 2021 levels. The cumulative emissions reductions associated with CTP-funded projects from 2021 to 2030 account for nearly 5 percent of transportation GHGs emitted in California in 2021.[21] The estimated annual GHG emissions reductions fall by less than half from 2030 to 2035. The fueling infrastructure and vehicle projects are estimated to reduce NO_x emissions by 156 metric tons per year in 2030 and 66 metric tons per year in 2035, and $PM_{2.5}$ emissions by 5.5 metric tons per year in 2030 and 2 metric tons per year in 2035.

[21] CARB. 2023. "Current California GHG Emission Inventory Data: 2000-2021 GHG Inventory (2023 Edition)." Available at https://ww2.arb.ca.gov/ghg-inventory-data.

Figure 3: Annual Expected Benefits by Project Class

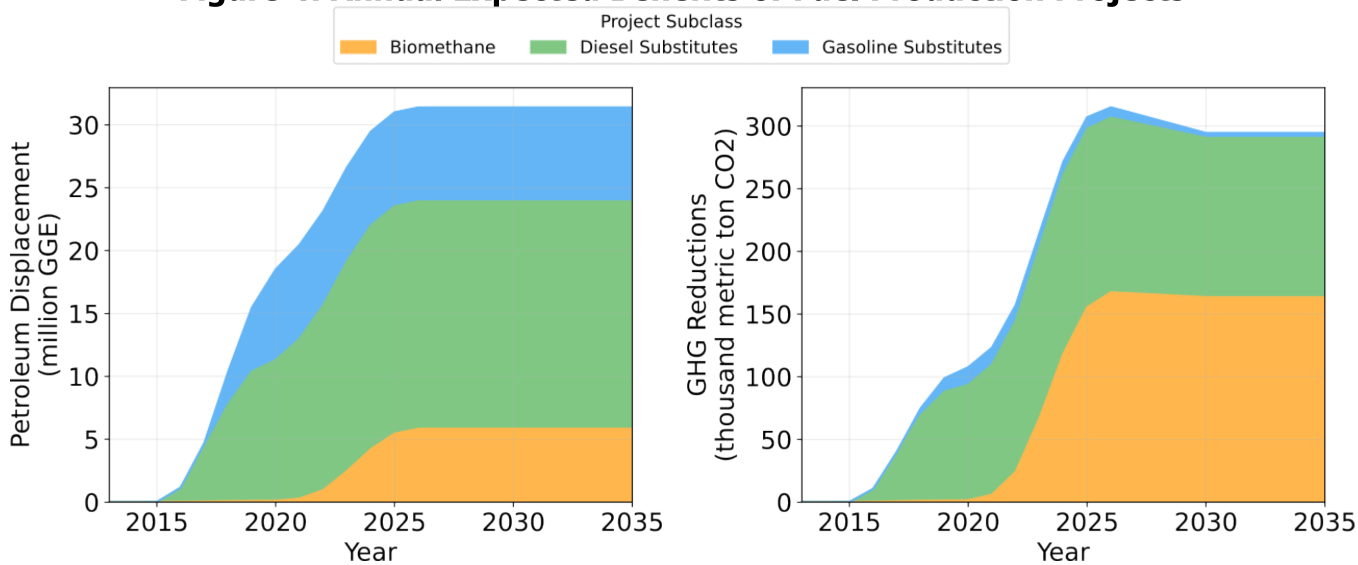


Source: NREL

Fuel Production Projects

Fuel production projects generate the largest share of GHG emissions reductions through 2024 before peaking in 2025 and plateauing (Figure 3) due to a shift in CEC funding toward ZEV-focused projects in recent years (Figure 2). The vast majority of GHG benefits from fuel production projects are due to diesel substitutes and biomethane. Diesel substitutes refer primarily to biomass-based diesel, which comprises biodiesel and renewable diesel. There is also one renewable dimethyl ether production project funded by CEC. From 2025 to 2035, diesel substitutes account for approximately two-thirds of the petroleum reductions, while ethanol and biomethane account for the remaining third in approximately equal proportions. Gasoline substitutes refer primarily to ethanol projects, with the exception of one renewable gasoline production project. The relative contributions to GHG emissions between the three fuel types looks much different than petroleum reductions due to CIs of the fuels. Figure 4 shows the annual expected benefits from the fuel production projects. Note that NO_x and $PM_{2.5}$ reductions are not estimated for fuel production projects.

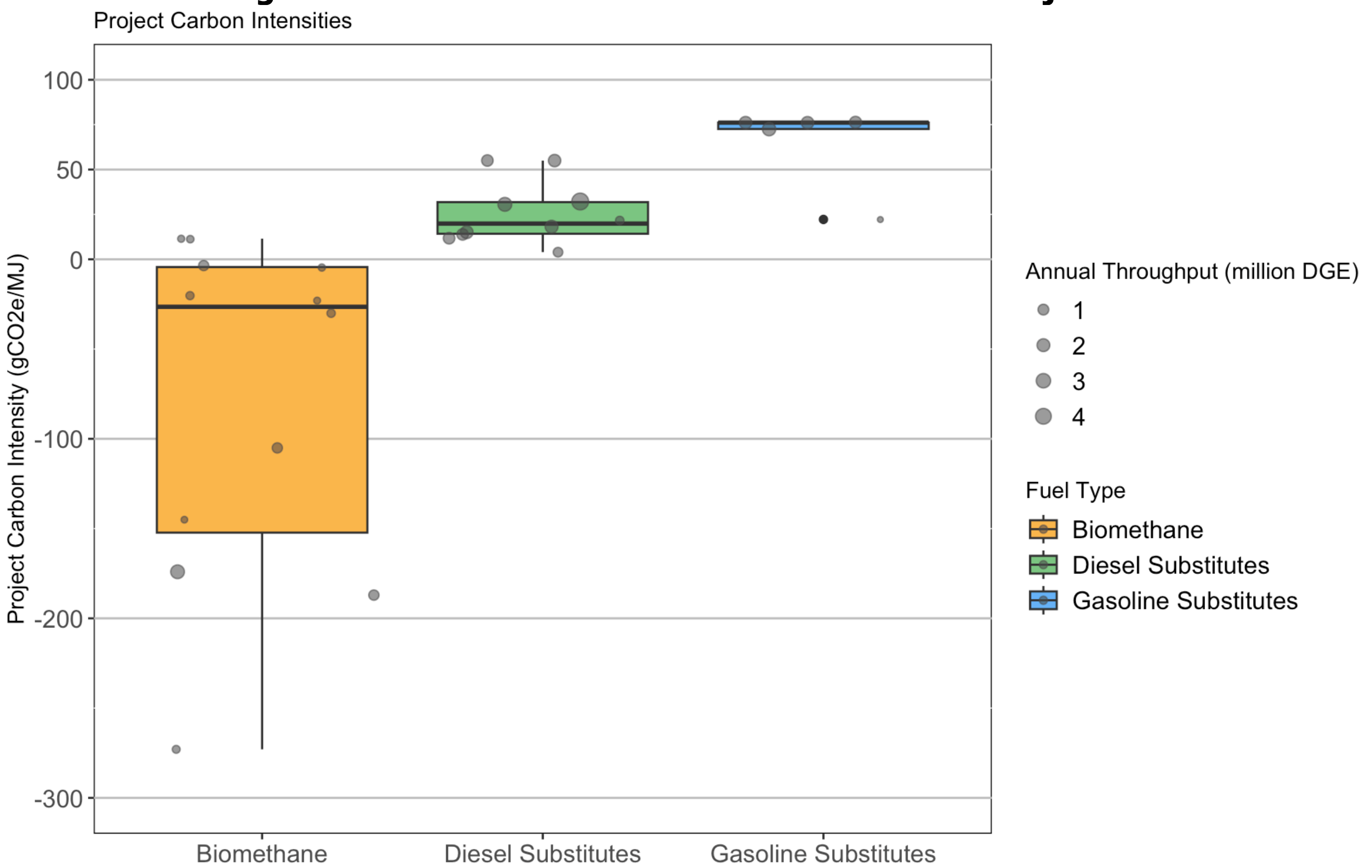
Figure 4: Annual Expected Benefits of Fuel Production Projects



Source: NREL

The differences between petroleum displacement and GHG emissions reductions are attributable to differences in CIs across the various fuels. Figure 5 shows the CI associated with the fuel production projects, broken down by fuel type. The points represent the CI of each individual project, and the size of each point represents the annual production volume for each project. The box plots represent the minimum, maximum, average, and interquartile range of CIs by fuel type. Biomass-based diesel displaces more petroleum than biomethane and ethanol combined over the modeling horizon, yet biomethane delivers greater GHG emissions reductions than ethanol and biomass-based diesel combined, beginning in 2026. The outsized impact of biomethane petroleum reductions on GHG emissions stems from the very low or negative CI associated with most biomethane projects. CIs of the biomethane projects funded by CEC range from −400 to 20 gCO_2e/MJ (Figure 5). Negative CIs reflect pathways where GHG emissions are avoided. Many of these projects produce biomethane from dairy digesters, municipal solid waste, food waste, and other pathways that capture methane that is assumed to have otherwise been emitted into the atmosphere. While gasoline substitutes contribute around a third of the petroleum reductions from 2025 onward, their expected GHG reductions are negligible because the majority of the fuel is ethanol produced from sorghum, which has a relatively high CI. Some of the ethanol projects will use cellulosic feedstocks, which have a lower CI but are expected to produce relatively less fuel than other ethanol projects (Figure 5).

Figure 5: Carbon Intensities of Fuel Production Projects

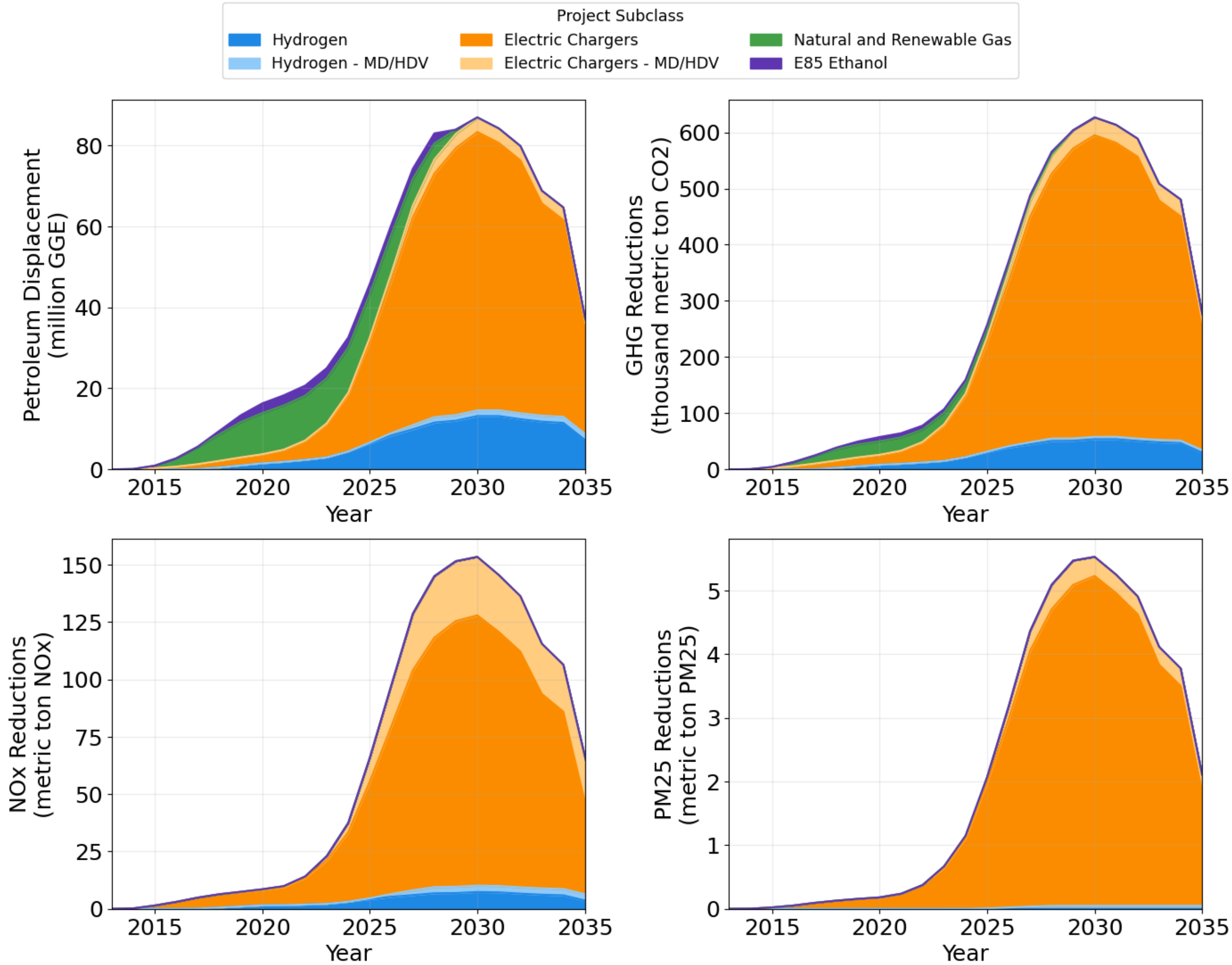


Source: NREL

Fueling Infrastructure Projects

Fueling infrastructure projects consist of EVSE, HRSs, natural gas and biomethane infrastructure, and E85 stations. Figure 6 shows the expected benefits associated with fueling infrastructure projects by the type of infrastructure. Until 2023, fossil and renewable natural gas infrastructure displaced more petroleum than all other types of fueling infrastructure combined. However, as the state has increasingly prioritized ZEV deployment in recent years, EVSE and HRSs are expected to account for the vast majority of petroleum displacement, GHG emissions reductions, and air pollution benefits moving forward.

Figure 6: Annual Expected Benefits of Fueling Infrastructure Projects



Source: NREL

ZEV fueling infrastructure projects are expected to generate an increasing share of the GHG emissions reductions over the next decade as more EVSE and hydrogen fueling infrastructure is deployed and more ZEVs are adopted. Expected GHG emissions reductions attributable to EV chargers increase rapidly from 2023 to 2030, growing 773 percent over the period, and peak at 569,000 metric tons in 2030 (Figure 6). Over that time period, EVSE for MD/HD vehicles accounts for between 3 and 6 percent of total EVSE GHG emissions reductions. GHG emissions reductions from hydrogen fueling infrastructure projects also increase significantly through 2030; however, they account for only 9 percent of all fueling infrastructure GHG emissions reductions in 2030. EVSE displaces more petroleum than hydrogen fueling infrastructure due to a combination of more chargers being deployed than hydrogen dispensers and chargers being utilized at a higher rate than hydrogen dispensers.

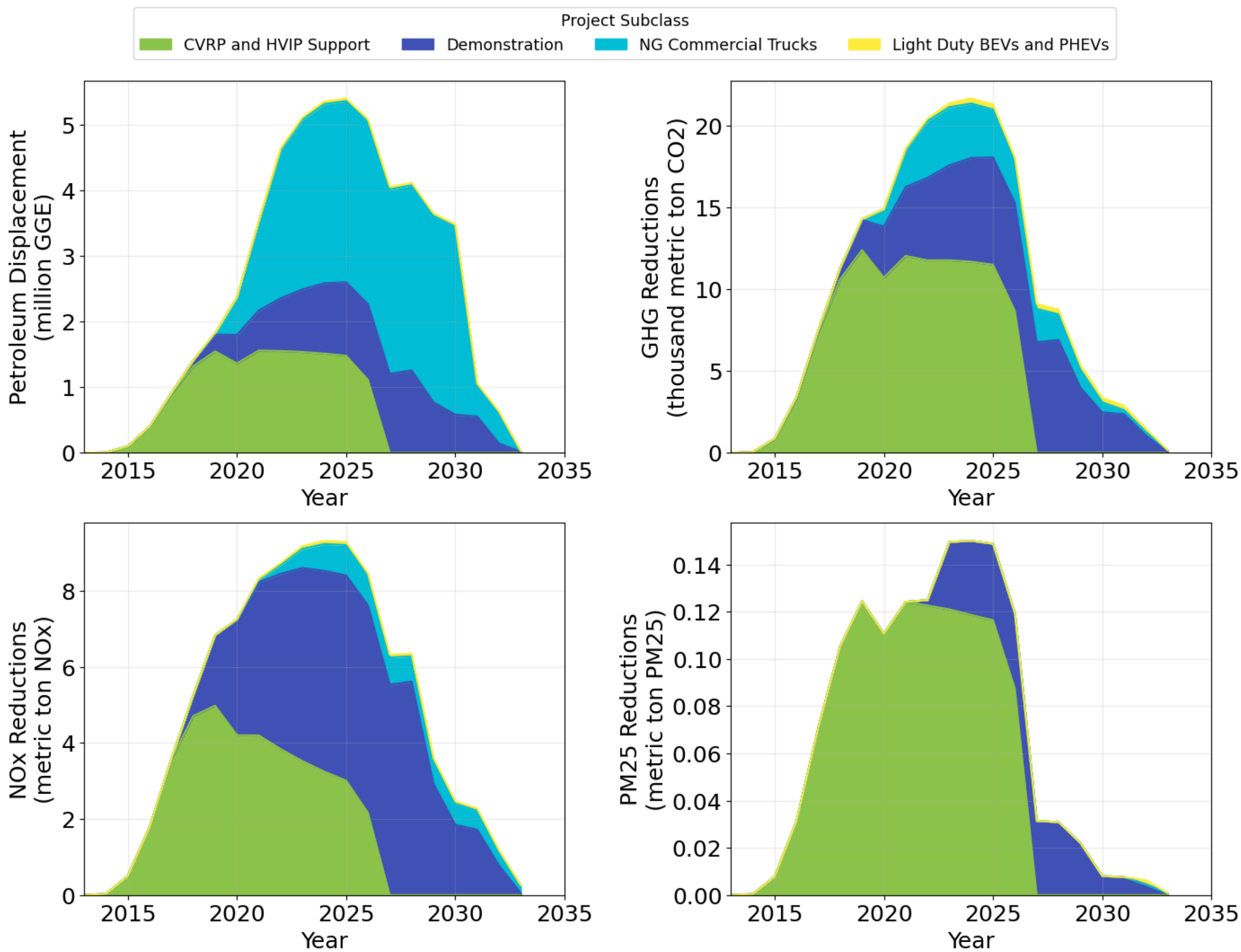
The vast majority of air pollution benefits are generated from LD EV chargers over the modeling horizon, generating 117 metric tons of NO_x emissions reductions and 5 metric tons of $PM_{2.5}$ emissions reductions in 2030. Electric charging infrastructure for MD/HD vehicles generates 26 metric tons of NO_x emissions reductions and 0.3 metric ton of $PM_{2.5}$ emissions reductions in 2030. Note that infrastructure for MD/HD vehicles has an outsized impact on NO_x

reductions relative to infrastructure for LD vehicles given the relatively higher NO_x emissions factors associated with diesel vehicles.

Vehicle Projects

The vehicle projects consist of the California Clean Vehicle Rebate Project (CVRP) and Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP) Support projects, vehicle demonstration projects, natural gas commercial truck projects, and LD BEV and PHEV projects. Figure 7 shows the estimated annual petroleum displacement, GHG emissions reductions, NO_x emissions reductions, and $PM_{2.5}$ emissions reductions associated with each type of vehicle project. As noted above, the vehicle projects are estimated to provide far fewer benefits than the other project classes. Among the vehicle project types, natural gas commercial truck projects displace more petroleum than other vehicle project types after 2020; however, these projects provide only a small share of GHG emissions reductions due to the relatively higher CI of natural gas.

Figure 7: Annual Expected Benefits of Alternative Vehicle Projects



Source: NREL

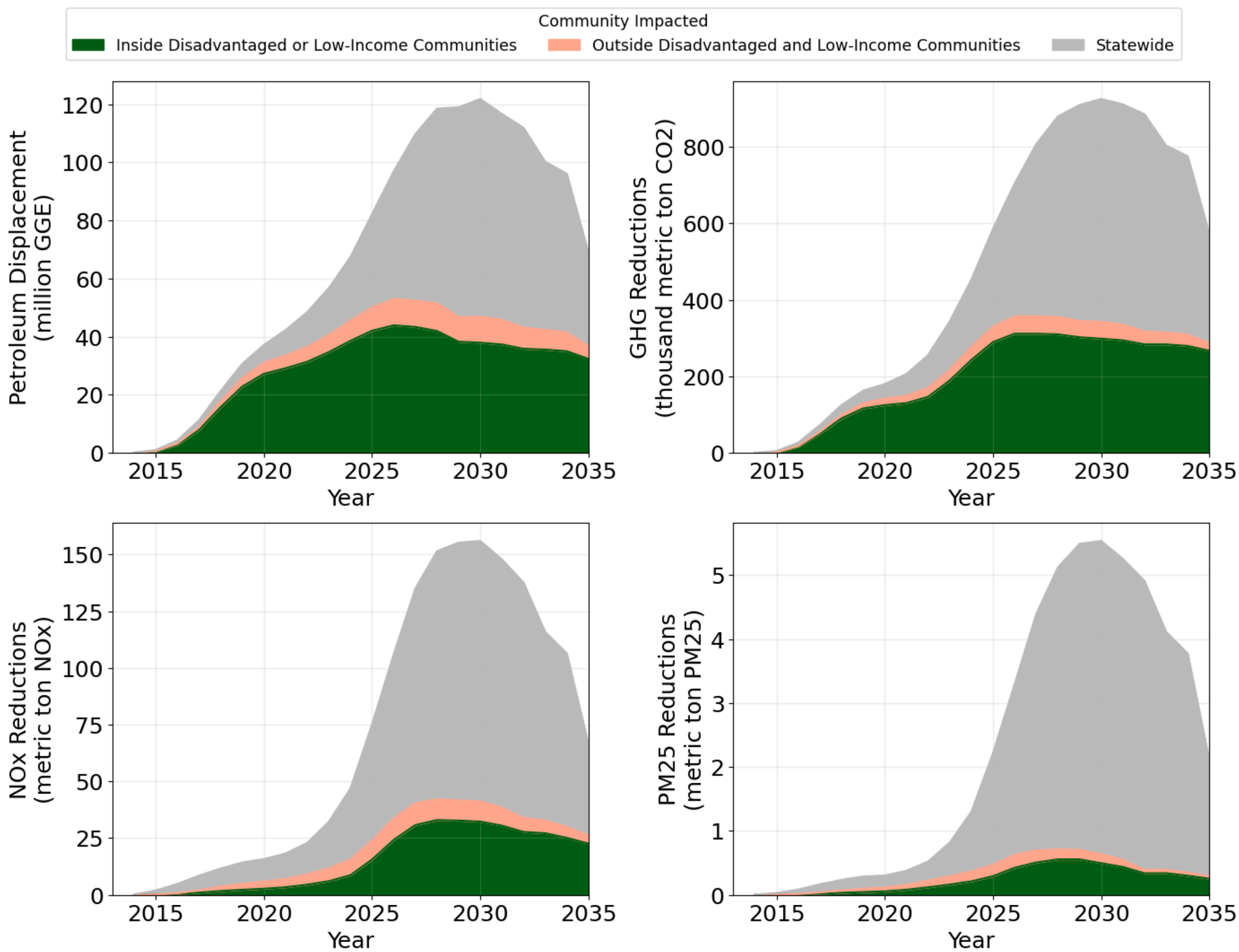
Expected benefits from vehicle projects generally peak in 2025 and decline through 2035 due to a decline in the number of projects funded by CEC over that latter time period. In 2025, the vehicle projects are estimated to displace slightly over 5 million GGE and reduce over 20,000 metric tons of CO_2e. They are also estimated to generate around 9 metric tons of NO_x

emissions reductions and less than one-fifth of a metric ton of $PM_{2.5}$ emissions reductions. Expected benefits associated with vehicle projects are estimated to fall to zero across all benefit categories by 2033.

Equity and Social Benefits

To estimate equity and social benefits, a spatial disaggregation is performed such that the benefits are regionalized throughout California. Geospatial attributes are available only for a subset of projects included in this analysis. Projects without geospatial attributes are assumed to be "statewide" projects. We match the geospatial attributes (address or latitude/longitude coordinates) to census tracts that are designated as a disadvantaged or low-income community. We assume that benefits accrue to the census tract in which the project is located. Figure 8 shows the annual expected benefits assigned to disadvantaged or low-income communities, outside these communities, or statewide.

Figure 8: Annual Expected Benefits for All Project Types by Community Type



Source: NREL

Figure 8 highlights the fact that the majority of petroleum and GHG reductions accrue to disadvantaged or low-income communities through 2025, at which point statewide projects generate the majority of benefits. The shift in petroleum and GHG emissions reductions toward statewide projects after 2025 is primarily a result of California Electric Vehicle Infrastructure Project (CALeVIP) projects coming online, which are all assumed to be statewide. For NO_x and $PM_{2.5}$ emissions reductions, the majority of benefits are generated from projects designated as statewide. By 2030, 87 percent of GHG emissions reductions from projects with geospatial attributes are attributable to disadvantaged or low-income communities, and 78 percent of NO_x and $PM_{2.5}$ emissions reductions from projects with geospatial attributes are attributable to disadvantaged or low-income communities.

CHAPTER 3: Market Transformation Benefits

As in the 2021 benefits report, market transformation benefits are based on data that are relatively more uncertain, and the estimation approaches are inherently more theoretical than those used to generate expected benefits. Market transformation benefits accrue due to the influence of CTP-funded projects on fundamental market forces to accelerate the adoption of advanced vehicle and fuel technologies. Shifting market forces or reductions in market barriers occur through mechanisms that are distinct from the expected benefits calculated in Chapter 2, and the two categories are therefore considered additive. Two main sets of market transformation influences are evaluated, each occurring through one or more CTP project types:

1. Vehicle perceived price reductions

a. Reductions in the perceived price of PEVs due to increased availability of public EVSE stations

b. Reductions in the perceived price of FCEVs due to increased availability of hydrogen stations.

2. Vehicle cost reductions

a. Reductions due to direct investments in production

b. Reductions due to increased experience or "learning by doing" associated with deploying additional units.

This updated report relies upon the same market transformation calculation framework used in the 2021 benefits report. Where new project or market data have become available, input values and parameters are updated accordingly. Refer to Section 3.1 in the 2014 benefits report for a detailed explanation of the methods' mathematical formulation.[22]

Vehicles Perceived Price Reduction

Price reductions of advanced vehicles (e.g., hybrid electric gasoline vehicles) tend to increase sales and displace conventional or competing vehicles. Projects funded by the CTP tend to increase sales through perceived price reductions due to increased availability of recharging infrastructure and hydrogen fueling infrastructure. The analytic framework relied upon to represent these market influences is reviewed in Section 3.1.1 of the 2014 benefits report. In this report, only an overview is provided of the main equations[23] used to estimate increased market share as a result of a vehicle price change.[24] Additional sales in numbers of vehicles

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[22] Melaina, M., E. Warner, Y. Sun, E. Newes, and A. Ragatz (NREL). 2014. *Program Benefits Guidance: Analysis of Benefits Associated with Projects and Technologies Supported by the Alternative and Renewable Fuel and Vehicle Technology Program*. California Energy Commission. Publication Number: CEC-600-2014-005-D.

[23] Melaina, M., J. Bremson, and K. Solo. 2012. "Consumer Convenience and the Availability of Retail Stations as a Market Barrier for Alternative Fuel Vehicles." in *31st USAEE/IAEE North American Conference*, Austin, Texas. Available at https://www.nrel.gov/docs/fy13osti/56898.pdf.

[24] Greene, D. 2001. *TAFV Alternative Fuels and Vehicles Choice Model Documentation*. Oak Ridge, Tennessee: Oak Ridge National Laboratory.

sold per year (ΔQ) due to reduced price are calculated as the product between the change in market share (S) and the total base sales of the incumbent and advanced vehicles. The additional sales are calculated as follows:

$$\Delta Q_{alt} = \left(S\left(P^{*}_{alt}, P_{ref}\right) - S\left(P_{alt}, P_{ref}\right)\right) \cdot \left(Q_{alt} + Q_{ref}\right)$$

where P_{alt} is the initial price of the alternative vehicle, P^{*}_{alt} is the price of the alternative vehicle resulting thanks to CTP project funding, P_{ref} is the price of the conventional vehicle, Q_{ref} represents the annual sales of the conventional vehicle within the market segment, and Q_{alt} is the initial annual sales of the alternative vehicle. The sales shares are determined as a function of the conventional and alternative vehicle prices according to a logit formulation:

$$S\left(P^{*}_{alt}, P_{ref}\right) = \frac{\exp\left[\mu\left(P^{*}_{alt} - P_{ref}\right)\right]}{1 + \exp\left[\mu\left(P^{*}_{alt} - P_{ref}\right)\right]}$$

$$S\left(P_{alt}, P_{ref}\right) = \frac{\exp\left[\mu\left(P_{alt} - P_{ref}\right)\right]}{1 + \exp\left[\mu\left(P_{alt} - P_{ref}\right)\right]}$$

where μ is the price slope. With this functional form, if the prices of the two vehicles are identical (i.e., $P_{alt} = P_{ref}$), the market share is 50 percent for both vehicles, regardless of the value of the price slope. This is interpreted as consumers having no attributes with greater or lesser value than others, and therefore having an equal probability of choosing one vehicle or the other. This is a very simplified representation of the consumer decision-making process; several non-price attributes affect the decision to purchase a vehicle. If prices are not equal, the influence of the difference on market share does depend upon the value of the price slope, calculated as:

$$\mu = \frac{\beta}{P(1 - s)}$$

where β is the demand elasticity for the market segment, P is the price point for the market segment, and s is the base market share of the market segment. Example calculations are presented and discussed in Section 3.1.1 of the 2014 benefits report.

Increased Availability of Fueling Infrastructure

Availability of EVSE and hydrogen fueling infrastructure is critical to the choice of adopting a ZEV. While PHEVs and BEVs may have private charging in some locations, public charging access increases consumer convenience and increases the perceived value of the PHEVs and BEVs. Unlike BEVs and PHEVs, hydrogen vehicles cannot refuel without public refueling stations.

As in the 2021 benefits report, each fueling infrastructure technology is analyzed by determining a reduction in the vehicles' perceived prices due to the availability of CTP-funded refueling stations. This reduction in perceived price is then used to estimate the increase in market share, the ZEV sales supported by CTP funding, and finally the resulting benefits due to the increased ZEV deployment. EVSE and HRS benefits are evaluated independently in the next sections.

Increased Availability of EVSE

This section attempts to quantify the effect of increased EVSE availability on vehicle adoption and the associated benefits through the lens of market transformation. Table 4 presents the

CTP-funded EVSE projects in California's four major metropolitan areas. EVSE that falls outside these zones has been labeled "Non-Urban."

Table 4: CTP-Funded LD EV Charging Ports by Urban Area (Through 2023)

Urban Area	L2 Public Ports	DCFC Public Ports
Bay Area	643	105
Los Angeles	1,727	210
Sacramento	270	25
San Diego	407	36
Non-Urban	644	129

Source: NREL[25]

The quantification of the economic value (and perceived price reduction) of EVSE infrastructure in this report follows the methodology in the 2021 benefits report used to determine a "willingness to pay" (WTP) metric.[26] WTP takes into account vehicle range, existing charging infrastructure, energy prices, income, and annual VMT. There are three functions used to calculate the WTP: PHEV value of EVSE, BEV intraregional value of EVSE, and BEV interregional value of EVSE (DCFC only). For PHEVs, WTP is estimated as follows:

$$WTP_{ij} = \left[f\left(\frac{I_j}{X_j}, R_i\right) - f(0, R_i)\right] M_{ij} \left(p_{jG} e_{iGs} - \left(p_{jG} e_{iGd} + p_{jE} e_{iEd}\right)\right) D_{ij}$$

For the BEV intraregional value of EVSE, WTP is estimated as:

$$WTP_{ij} = \left[\left(a_0 + a_1 \ln\left(\frac{I_j}{X_j}\right)\right)\left(\frac{b_0}{R_i^{b_1}}\right) M_j \left(v_j - \frac{w_j}{\phi R_i}\left(K\left(\left(\frac{I_j}{X_j}\right)^{\alpha} - \left(\frac{I_j}{X_j}\right)^{\alpha}\right) + \frac{\phi R_i e_i}{d}\right)\right)\right] D_j$$

Finally, for the BEV interregional value of EVSE, WTP is described by:

$$WTP_{ij} = \left[\left(a_1\left(\frac{I_j}{X_j}\right) + a_2\left(\frac{I_j}{X_j}\right)^2 + a_3\left(\frac{I_j}{X_j}\right)^3\right)\left(e^{-b(R-R_0)}\right) M_j \left(v_j - \frac{w_j}{\phi R_i}\left(K\left(\left(\frac{I_j}{X_j}\right)^{\alpha} - \left(\frac{I_j}{X_j}\right)^{\alpha}\right) + \frac{\phi R_i e_i}{d}\right)\right)\right] D_j$$

In brief, the value of WTP for PHEVs depends on annual miles driven and the difference between the cost of electricity and the cost of gasoline as a fuel. On the other hand, BEV

[25] Included in this analysis are only the charging stations for which geographical location was provided (25 percent of all CTP-funded stations).

[26] Greene, David L., Matteo Muratori, Eleftheria Kontou, Brennan Borlaug, Marc Melaina, and Aaron Brooker (NREL). 2020. *Quantifying the Tangible Value of Public Electric Vehicle Charging Infrastructure*. California Energy Commission. Publication Number: CEC-600-2020-004.

interregional values depend on the number of chargers in a given geographical area in relation to the number of chargers required for full electrification, as well as annual miles traveled, the value of an electric mile to a BEV owner, and the expected value of their time. The value of the BEV owner's time is used to represent the value of charging at higher speed. BEV interregional value is estimated in a similar fashion to intraregional, with the exception that vehicle range plays a more important role in the value, and that L2 chargers are not considered a viable charging option. Finally, all equations include a discount rate to account for value over time. Table 5 provides a detailed list of the variables and their definition.

Table 5: WTP Variables

Variable	**Description**
i	Indexed region
j	Indexed vehicle
WTP	Willingness to pay in discounted present value dollars per new vehicle
f	Electric miles as a fraction of miles of a comparable conventional vehicle
X	Number of charging stations required for full electrification
R	Vehicle's rated range (miles)
M	Annual miles of a comparable conventional vehicle
p_{jg}	Price of gasoline fuel ($/gal)
p_{jE}	Price of electricity ($/kWh)
e_{iGs}	Gasoline use per mile of PHEV in charge-sustaining (s) mode
e_{iGd}	Gasoline use per mile of PHEV in charge-depleting (d) mode
e_{iEd}	Gasoline use per mile of PHEV in charge-depleting (d) mode
D	Discount factor
w	Value of time ($/minute)
v	Value of one mile of enabled EV travel
ϕ	Minimum EV charge at which a driver would normally recharge
d	Charging rate (kW)
$a_0, a_1, a_2, a_3, b, b_0, b_1, K, \alpha$	Coefficient estimates

Source: NREL, adapted from Greene et al. 2020

As previously mentioned, a consequential assumption in this methodology is the projected number of EV chargers required for the full electrification of the state of California's LD vehicles. The number of chargers assumed in this analysis is based on CEC's 2023 assessment of the state's charging needs, which concluded that 2,030,000 L2 and 83,000 DCFC charging ports are required statewide by 2035.[27] Assuming that public stations will be geographically distributed similarly to gasoline refueling stations, the numbers of required EV charging stations per urban area are calculated and shown in Table 6.

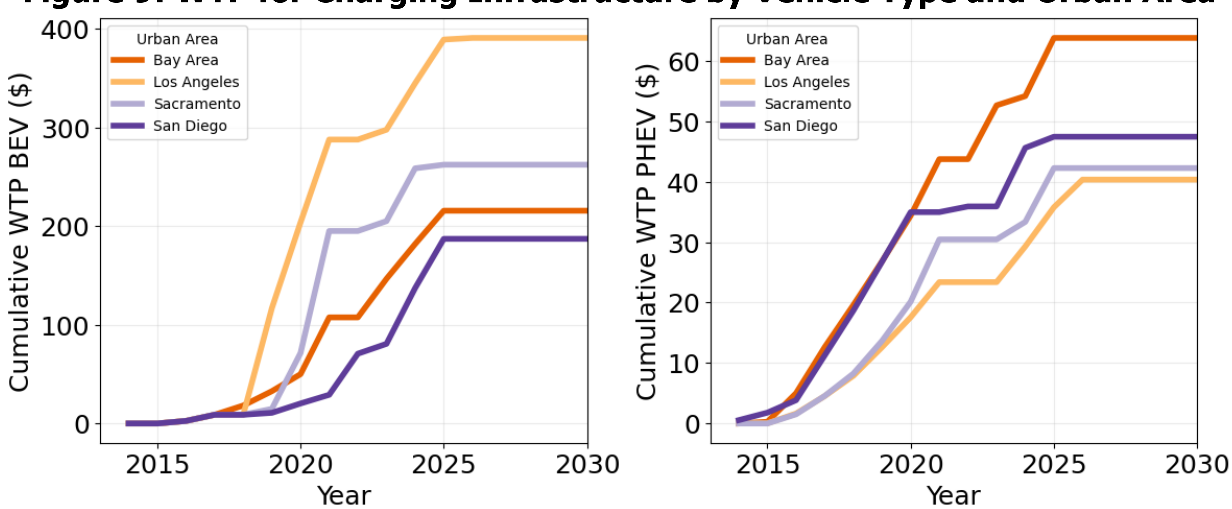
Table 6: Full Electrification Estimates

Urban Area	Gas Stations	Full Electrification L2 Stations	Full Electrification DCFC Stations
Bay Area	1,164	21,920	2,156
Los Angeles	2,813	52,974	5,209
Sacramento	378	7,119	700
San Diego	599	11,280	1,109
Non-Urban	3,315	62,428	6,139

Source: NREL

After CEC-funded EVSE is grouped into its proper urban areas, all other EVSE in the state is also assigned to its respective urban areas. Stations outside of the urban areas are considered connectors or interregional. On a year-by-year basis, the equations above are executed accounting for the median vehicle range and the number of non-CEC-funded stations in existence during each year. The annual outcomes are then aggregated to generate the total value to PEV owners. Cumulative WTP for both BEVs and PHEVs are shown in Figure 9 for different urban areas. As might be expected, the WTP of PHEVs is significantly lower than that of BEVs, mainly due to the stronger reliance of BEVs on public charging compared with PHEVs.

Figure 9: WTP for Charging Infrastructure by Vehicle Type and Urban Area

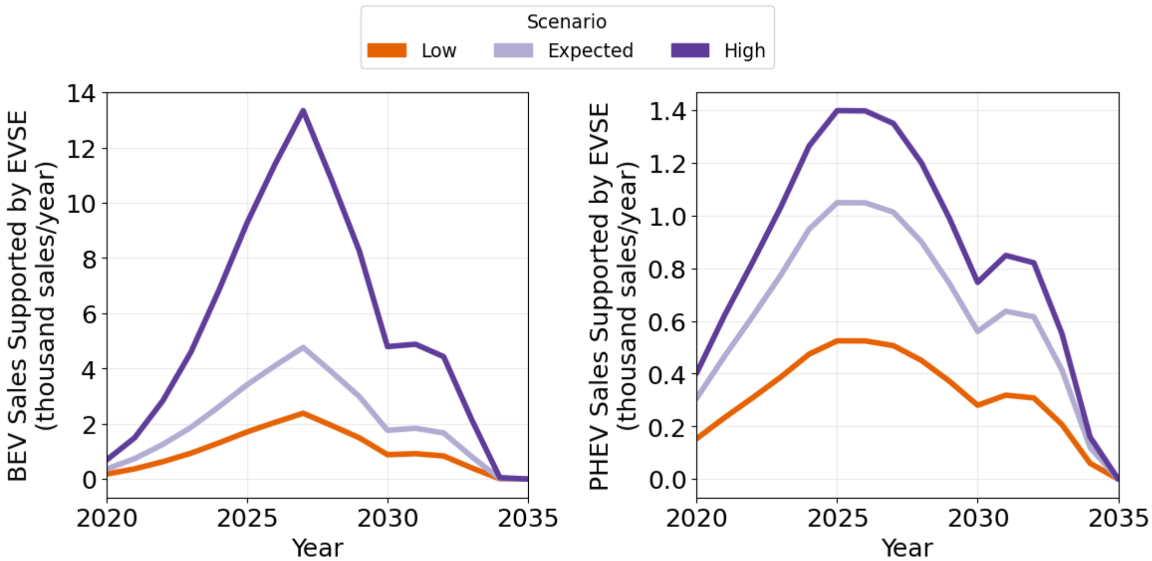


Source: NREL

[27] Davis, Adam, Tiffany Hoang, Thanh Lopez, Jeffrey Lu, Taylor Nguyen, Bob Nolty, Larry Rillera, Dustin Schell, and Micah Wofford. 2023. *Second Assembly Bill (AB) 2127 Electric Vehicle Charging Infrastructure Assessment: Assessing Charging Needs to Support Zero-Emission Vehicles in 2030 and 2035*. California Energy Commission. Publication number CEC-600-2023-048. Available at https://www.energy.ca.gov/publications/2023/second-assembly-bill-ab-2127-electric-vehicle-charging-infrastructure-assessment.

As previously described, the WTP values are translated into induced vehicles sales, shown in Figure 10. Three different scenarios are presented in this analysis: the *high* scenario directly uses the values of WTP calculated shown in Figure 9, while the *expected* and *low* scenarios use respectively 50 percent and 25 percent of those values. Consistent with results on WTP for PHEVs and BEVs, sales for the latter vehicle type are approximately tenfold those of the former. Moreover, a lot of variability can be observed across the different scenarios analyzed, which shows the sensitivity of the results to WTP.

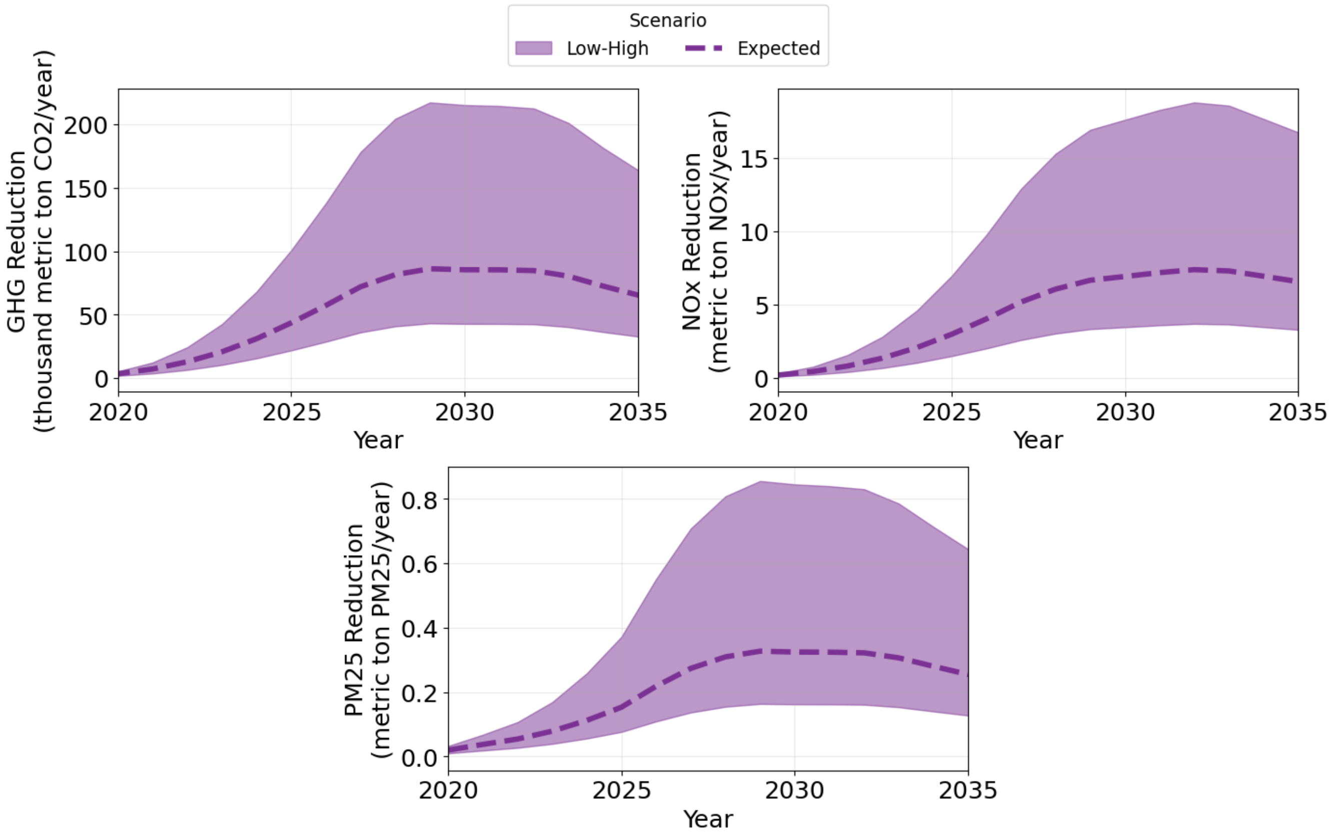
Figure 10: Additional PHEVs and BEVs Deployed Due to an Increase in Public EVSE Availability



Source: NREL

Finally, using expected vehicles characteristics such as VMT and GHG and pollutant factors (as explained in Chapter 2), environmental benefits associated with the additional deployment of EVs are calculated and shown in terms of reductions in GHG, NO_x, and $PM_{2.5}$ in Figure 11. Again, large variability is shown across analysis scenarios, while benefit trends in the different categories are somewhat similar: the rate at which the benefits accrue increases until approximately 2030, stabilizes until 2032, and finally starts decreasing through 2035.

Figure 11: Environmental Benefits From Additional Personal LD EVs Deployed Due to an Increase in EVSE Availability



Source: NREL

Influence of Availability of HRSs

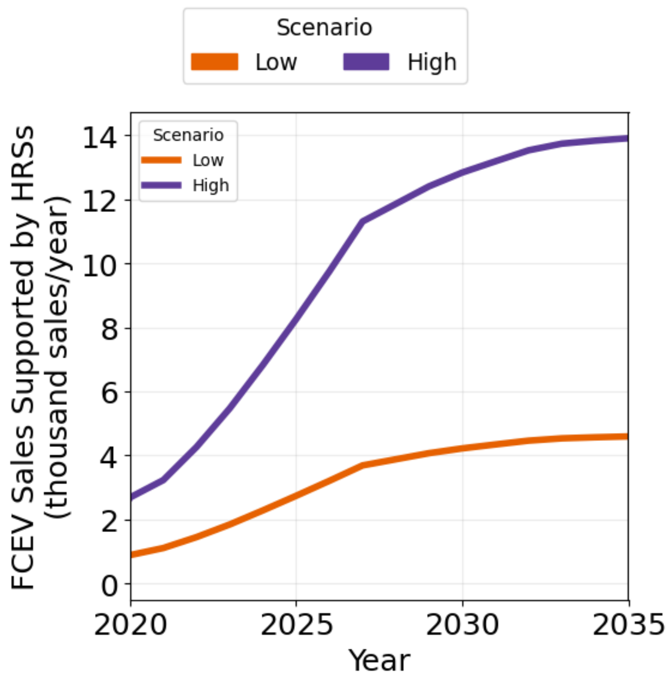
As in the 2021 benefits report, the authors estimate the impact of CTP-funded HRSs in decreasing the perceived price of FCEVs, and thus generating additional sales and environmental benefits. In this case, the reduction in perceived vehicle price is presented for both urban and intercity travel as marginal improvements due to CTP-funded refueling stations to baseline economic penalties associated with scarce fueling infrastructure availability. The cost penalties are estimated as a function of HRS availability using discrete consumer choice surveys and are spatially resolved by specific urban area.[23] The approach used in this report is the same as the 2021 benefits report, which is ultimately based on the methodology explained in detail in the 2014 benefits report.

For urban areas, the functions defining the penalties are natural log curves with parameters based on the specific area's population, so that the impact of HRSs in a certain urban area is exponentially lower as HRS availability increases. The coefficients used are the same as those in the 2021 benefits report. On the other hand, the intercity cost penalty reductions are calculated assuming a linear relationship between HRS availability along interstates and the associated penalty reduction. As in the 2021 benefits report, an initial penalty of $2,000 is used and reduced by $333 for each station installed along the interstate. Then, the marginal improvements due to CTP-funded HRSs to both the urban and intercity penalties are used as perceived reductions in FCEV prices, through which the increase in FCEV market share and additional sales can be calculated. In order to address some of the uncertainty regarding the size of the FCEV market, impacts are estimated for two early adopter market segments (2.5 percent and 10 percent of LD vehicle sales) and at two vehicle price points ($65,000 and

$50,000) in low- and high-adoption scenarios, respectively. Refer to the 2021 and 2014 benefits reports for additional details with regard to this methodology.

Figure 12 displays the resulting high and low increased FCEV sales estimates due to the influence of all CTP-funded stations. Additional FCEV sales in the low case (2.5 percent market segment and $65,000 per vehicle) are just under 3,000 vehicles per year in 2025 and ramp up to more than 4,000 by 2030. On the other hand, the additional annual FCEV sales for the high case (10 percent market segment and $50,000 per vehicle) are expected at just more than 8,000 vehicles per year in 2025 and ramp up to nearly 13,000 FCEVs per year in 2030 and close to 14,000 by 2035. This growth indicates that the price point and market segment are critical to determining the relative effect of the CTP awards for HRSs.

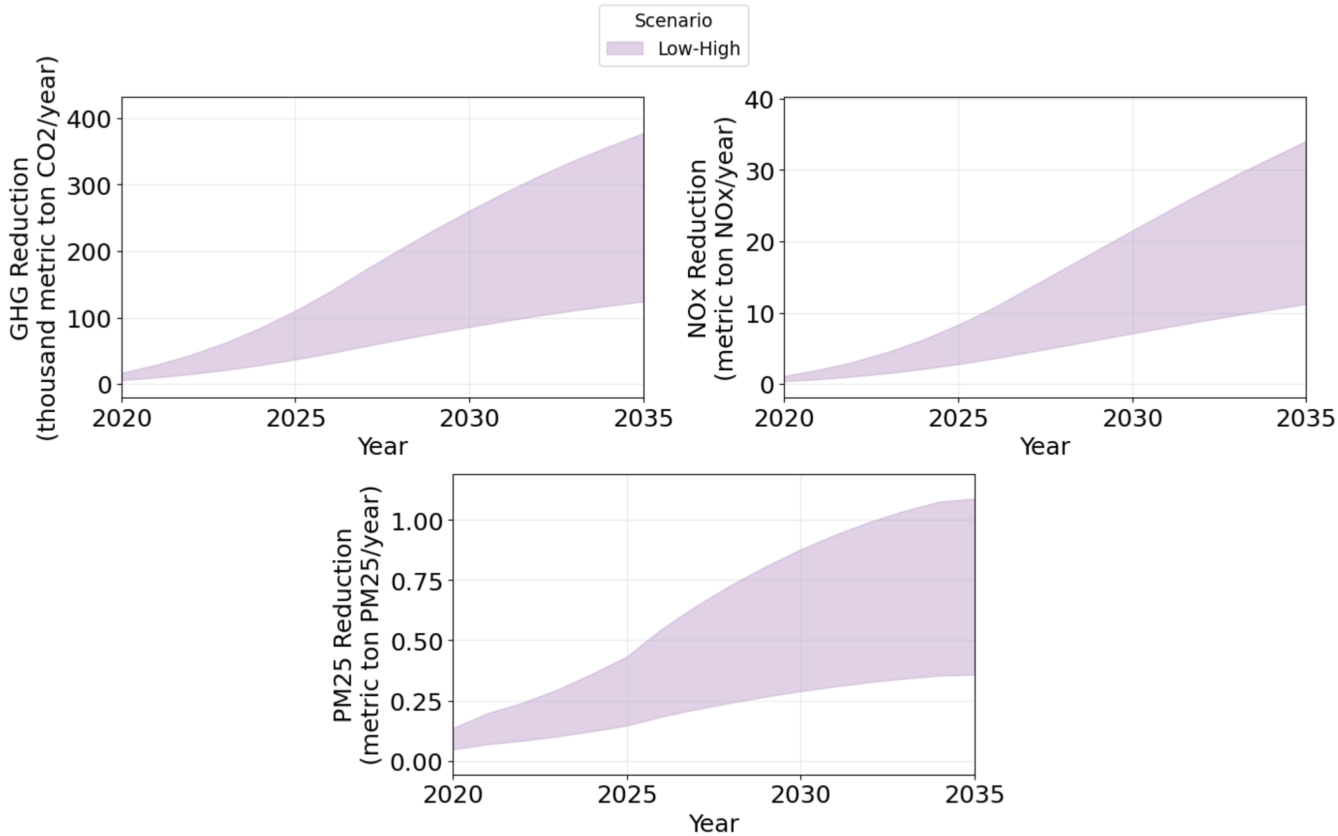
Figure 12: Additional FCEVs Sold Due to Installation of HRSs



Source: NREL

The environmental benefits resulting from the increase in FCEV sales are summarized in Figure 13 in terms of GHG reductions and improvements in NO_x and $PM_{2.5}$ air pollution. Again, appreciable variability is shown for the two scenarios analyzed, while the trends are fairly consistent between pollutants, which all see benefits accruing at an increasing rate through 2035 due the number of CTP-funded refueling stations projected to still be active by then.

Figure 13: Environmental Benefits From Additional Personal LD FCEVs Deployed Due to an Increase in HRS Availability



Source: NREL

Influence of Investments in Manufacturing

Total benefits resulting from investments in EV manufacturing processes (including components and direct production) are calculated based on CTP funding allocated to each of the projects in the manufacturing subclass. The methodology utilized is the same as in the 2021 CTP benefits report, which is originally presented in detail in the 2014 report. In brief, the methodology for calculating these benefits assumes that investments in manufacturing processes and components drive down production costs, and that in turn, part of these reductions are passed down to consumers in the form of reduced vehicle prices. Then, similarly to other categories of market transformation benefits, price reductions are correlated with an increase in EV market share, additional vehicles sales, and resulting environmental benefits.

In line with the methodology shown in the 2014 benefits report, the updated production cost (P_{new}) of the vehicle can be calculated as:

$$P_{new} = P_0 \left(\frac{Q_{new}}{Q_0}\right)^{-b}$$

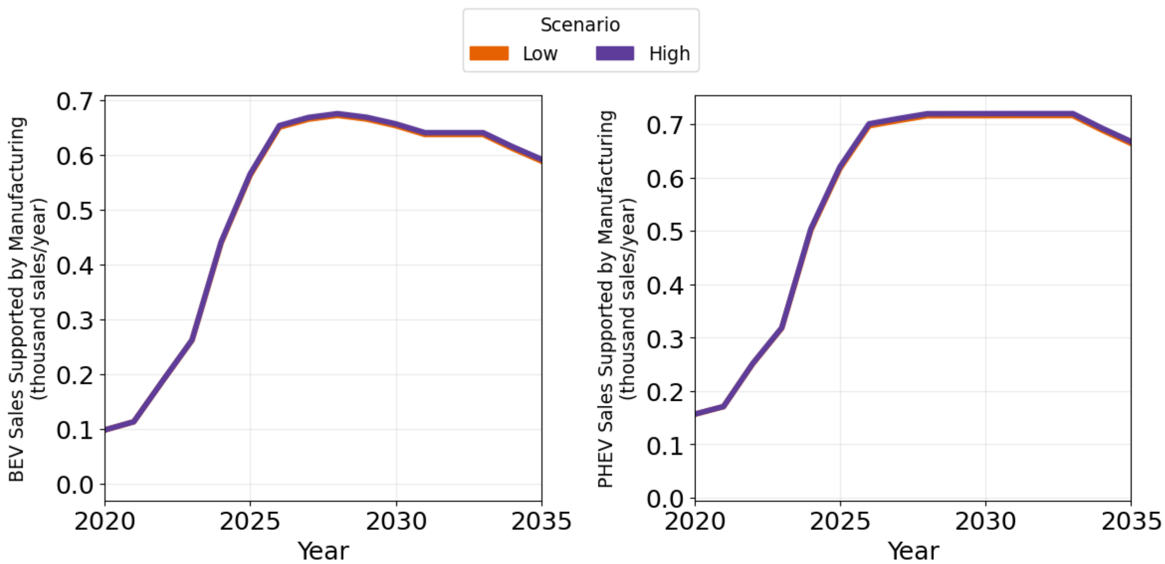
where P_0 is the original production cost, Q_0 and Q_{new} are respectively the cumulative vehicles produced before and after the CTP investment, and finally b is the selected industry learning factor. Similar to previous analysis, learning factors of 0.01742 and 0.13289 are chosen for the low and high scenarios, respectively, and their calculations are shown in the 2014 report.

Then, the increased cumulative production of vehicles Q_{new} can be calculated as a function of the CTP investment I_{CTP} by numerically solving the following equation:

$$P_0 Q_{new}\left[1-\left(\frac{Q_{new}}{Q_0}\right)^{-b}\right]=I_{CTP}$$

Having obtained the updated vehicle production cost after CTP funding P_{new}, it is assumed that 60 percent of the reduction in production cost is passed down to consumers to calculate the updated vehicle selling price. Figure 14 shows the additional sales of BEVs and PHEVs following this methodology. The figure shows how the impacts of investments in manufacturing are quite similar across vehicle types, and almost identical in the two scenarios analyzed. Sales due to these investments increase until 2025, when they stabilize around 700 vehicles per year through 2035.

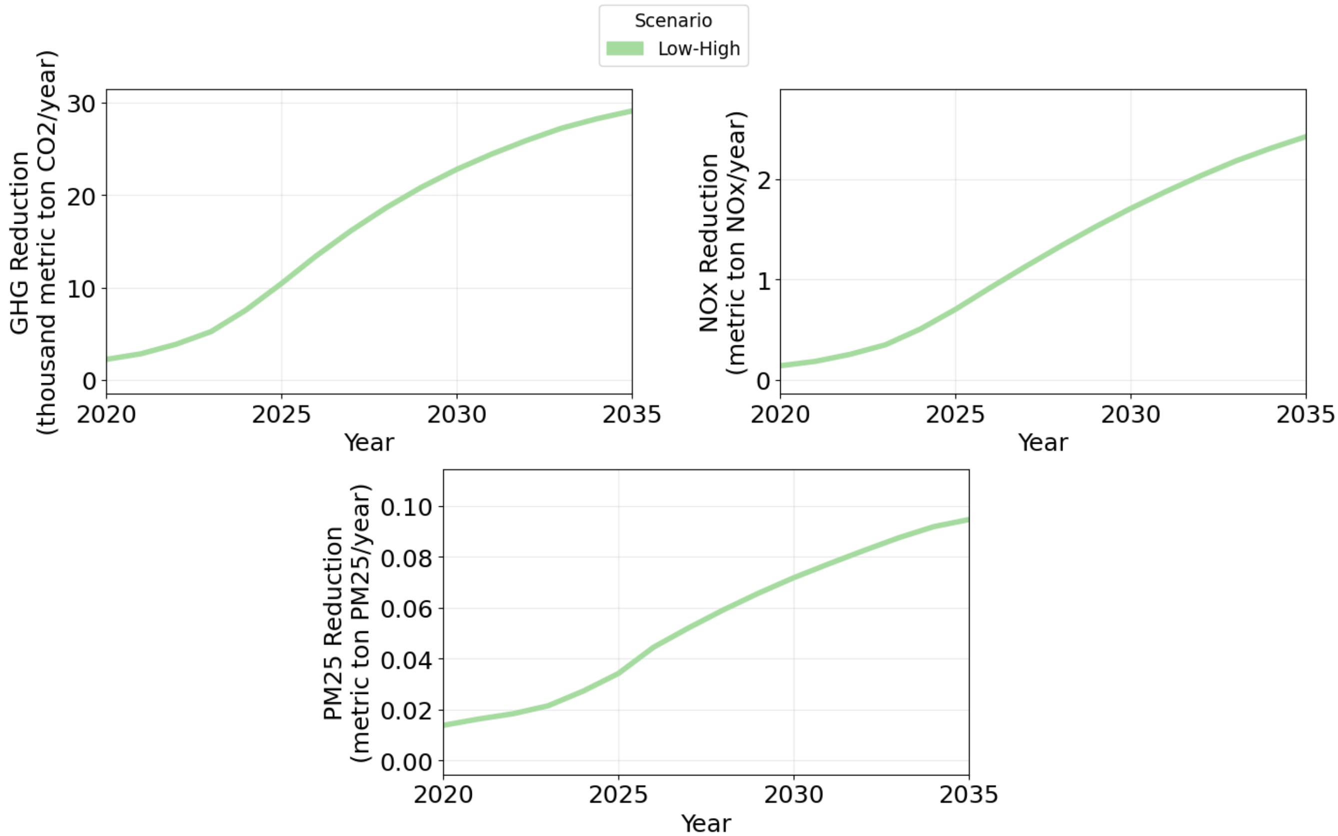
Figure 14: Additional EVs Sold Due to Investments in Manufacturing Processes



Source: NREL

Finally, Figure 15 shows the environmental benefits associated with CTP investments in manufacturing. Again, there is no perceptible difference between the low and high scenarios investigated; the rate at which benefits in all three categories accrue increases rapidly after 2025 to reach on average 31,000 metric tons of CO_2e per year, 2.6 metric tons NO_x per year, and 0.07 metric tons $PM_{2.5}$ per year by 2030.

Figure 15: Environmental Benefits From Investments in Manufacturing Processes



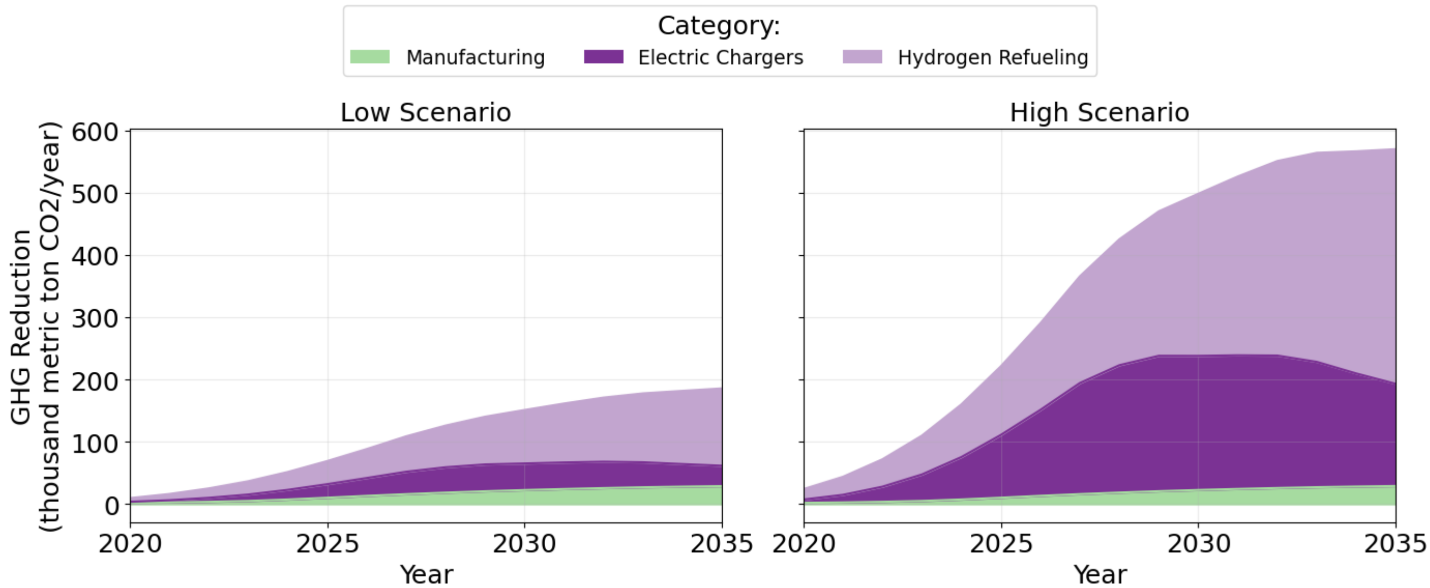
Source: NREL

Summary of Market Transformation Benefits

In the previous subsections, the methodologies and corresponding results are presented for three categories of market transformation benefits: perceived reduction in EV prices due to EVSE availability, perceived reduction in FCEV prices due to HRS availability, and reduction in alternative vehicle production costs due to investments in manufacturing processes and vehicle production. In this section, the same benefits are presented and compared across categories in the low and high scenarios.

First, Figure 16 shows the GHG reductions generated by market transformation thanks to CTP funding. As expected, there is essentially no difference between the two scenarios in terms of benefits due to investments in manufacturing, whereas there is a lot of variation in the other two categories. Although CTP funding to increase EVSE availability is significantly larger than that to HRSs, the latter category shows larger benefits because of the higher percentage of hydrogen projects reporting geographical information, which is necessary to calculate these benefits. Across benefits categories, CTP funding is expected to result in 69,270 metric tons CO_2e per year of GHG reductions in 2025 in the low scenario, increasing to 165,260 in 2030 and 186,000 in 2035. Conversely, in the high scenario, GHG reductions are expected to account for 221,600 metric tons of CO_2e per year in 2025, growing to 522,190 and 570,300 in 2030 and 2035, respectively.

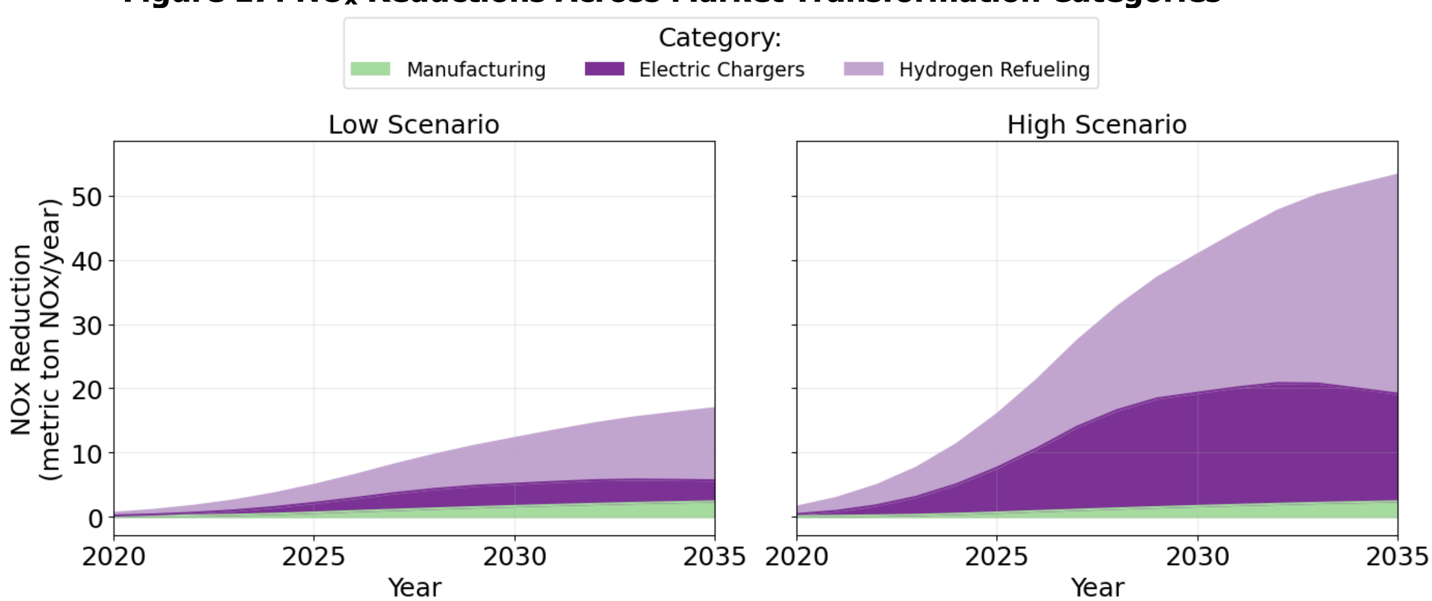
Figure 16: GHG Reductions Across Market Transformation Categories



Source: NREL

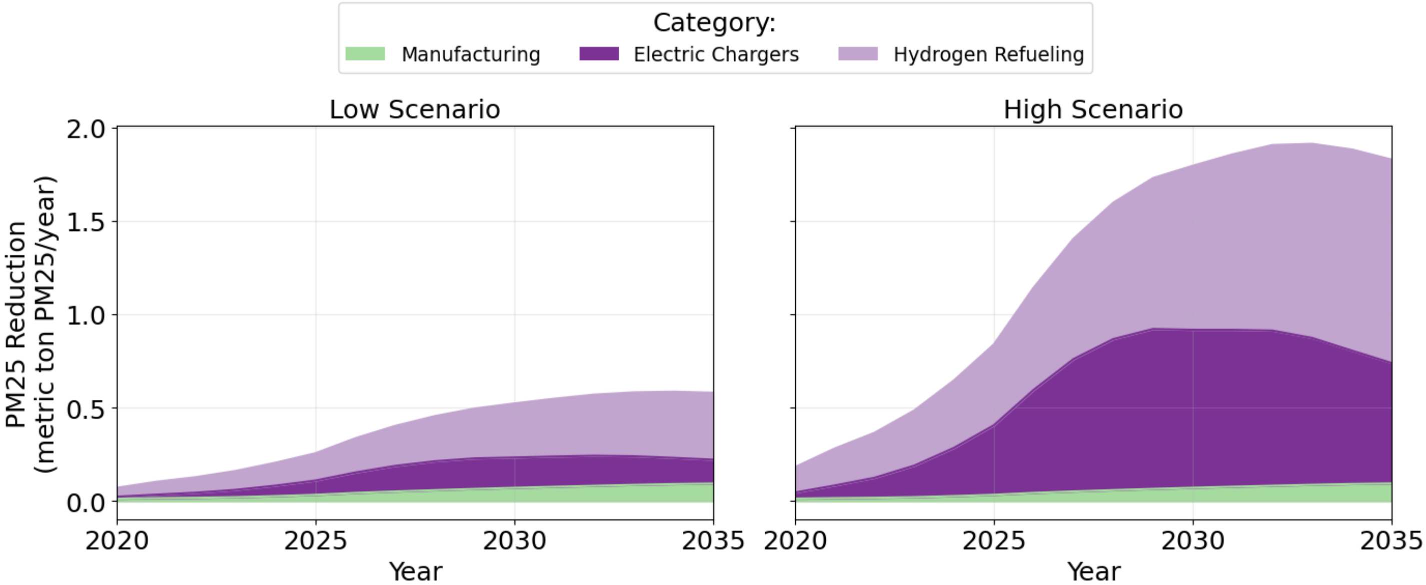
Finally, Figure 17 and Figure 18 show the improvements in criteria pollutants (NO_x and $PM_{2.5}$, respectively) resulting from the same market transformation benefits. While naturally the numerical values are quite different from those presented in Figure 16, the trends observed are quite similar: nearly identical benefits across scenarios due to investments in manufacturing, with large variability in the other two categories, with benefits due to HRS availibility being slightly larger than those due to investments in EVSE.

Figure 17: NO_x Reductions Across Market Transformation Categories



Source: NREL

Figure 18: $PM_{2.5}$ Reductions Across Market Transformation Categories



Source: NREL

CHAPTER 4: Economic Impacts Analysis

Investments supported by the CTP result in added economic impacts to the state of California and are expected to continue to stimulate the local economy throughout the lifespan of these projects. To estimate the effect of these investments in the state an input–output model is applied, which is one of the most used and straightforward methods for economywide impacts analysis resulting from a change in regional demand (e.g., a new construction project). For this analysis, the focus is on employment and occupation impacts in California.

Input–output models represent the structure of an economy as a network of sectors buying and selling to one another, to local households, government, and to external markets (exports). Its results reflect the supply chain's responses and the total macro-level impacts from changes in demand for goods and services in a region. Through a multiplier effect, an initial investment can reverberate throughout the economy and magnify its direct job impacts. The interdependence among sectors along the supply chains of equipment, materials and services required by the project supports additional jobs across the economy. Furthermore, the wages spent in the economy by those workers directly employed by the project and indirectly employed across supply chains also increase the number of jobs supported in the region (induced effects).

IMpact Analysis for PLANning (IMPLAN) is a platform for input–output modeling that provides state-level data to estimate the total impacts of structural changes (new industries, sector growth, and demand shocks) in a given region in terms of local jobs, gross domestic product, labor income, industrial output, and taxes. Underlying these analyses is a dataset of social accounting matrices that include sectoral, demographic, and governmental data reflecting how the economy of the region operates in a certain year. Social accounting matrices reflect economic flows between sectors, consumers, and institutions at the state, county, and ZIP code levels. Using California-specific multipliers derived from IMPLAN, direct, indirect, and induced jobs supported by CTP-funded projects over the 2013–2022 period and the expected project impacts up to 2027 are estimated.

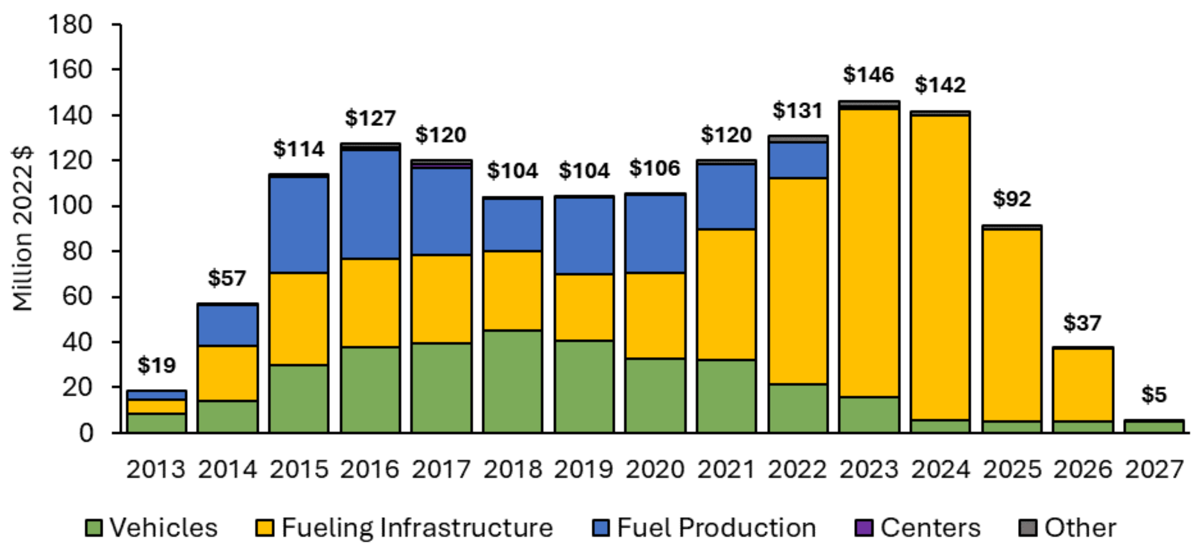
A total of $1.4 billion (2022 constant dollars) in direct investment is expected from 2013 to 2027, averaging $100 million in expenses per year (Figure 19). This includes CEC funds reimbursed to projects, as well as matching funds from awardees. Vehicle and fuel production projects are more prominent in the portfolio up to 2020, while fueling infrastructure investments (mainly electric charging and hydrogen fueling stations) pick up from 2021 until 2026.

IMPLAN's data for California are disaggregated in 546 sectors/commodities,[28] and thus the first step of the analysis requires allocating the projects' expenditures in materials, equipment, services, and contractors among those commodities. Expenses described in the project budgets are mapped to different commodities in IMPLAN according to their definitions. Nonetheless, emerging technologies such as different types of ZEVs, lithium-ion battery packs,

[28] Commodities refer to both goods and services.

and fuel cell systems have a small participation in the overall economy and therefore are not well captured in the model. For those, custom sectors are developed that represent BEV manufacturing, FCEV manufacturing, fuel cell system manufacturing, and lithium-ion battery pack manufacturing. BEV and FCEV industries are constructed according to Jeffers et al. (2022),[29] fuel cell manufacturing is based on data from James et al. (2017, 2018),[30] and lithium-ion manufacturing is based on data from Knehr et al. (2022).[31] Expenses on those goods are then allocated to the new custom sectors and mapped to IMPLAN commodities. Consequently, the employment results in this report are not directly comparable to the estimated number of jobs presented in the 2021 benefits report due to the updated methodology. Finally, because of the large number of projects funded, templates for different categories, subcategories, and vehicle types (when applicable) are created averaging the allocation from a sample of project budgets.

Figure 19: Total Investment (CEC) per Year, 2013–2027



Source: CEC

Figure 20 shows the distribution of expenditures by major goods/service groups for all years combined (million 2022 constant dollars). As expected, given the types of projects funded, professional services (which include engineering, architectural, and research services), manufacturing, and construction comprise the main expenses for the projects (84 percent).

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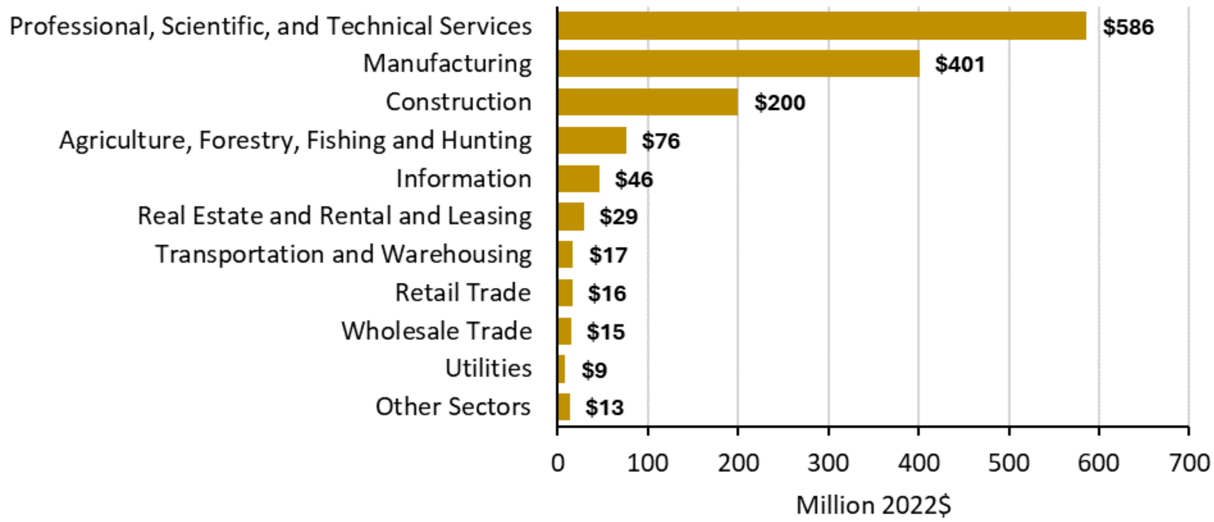
[29] Jeffers, M., K. Kelly, T. Lipman, A. Avelino, C. Johnson, M. Li, M. Post, and Y. Zhang. 2022. *Comprehensive Review of California's Innovative Clean Transit Regulation: Phase I Summary Report*. Golden, Colorado: NREL. NREL/TP-5400-83232. Available at https://www.nrel.gov/docs/fy23osti/83232.pdf.

[30] James, B., J. Huya-Kouadio, C. Houchins, and D. DeSantis. 2017. *Mass Production Cost Estimation of Direct H2 PEM Fuel Cell Systems for Transportation Applications: 2016 Update*. Strategic Analysis Inc.: Arlington, Virginia.

James, B., J. Huya-Kouadio, C. Houchins, and D. DeSantis. 2018. *Mass Production Cost Estimation of Direct H2 PEM Fuel Cell Systems for Transportation Applications: 2018 Update*. Strategic Analysis Inc.: Arlington, Virginia.

[31] Knehr, K., J. Kubal, P. Nelson, and S. Ahmed. 2022. *Battery Performance and Cost Modeling for Electric-Drive Vehicles: A Manual for BatPaC v5.0*. ANL/CSE-22/1. Argonne National Laboratory: Lemont, Illinois. Available at https://publications.anl.gov/anlpubs/2022/07/176234.pdf.

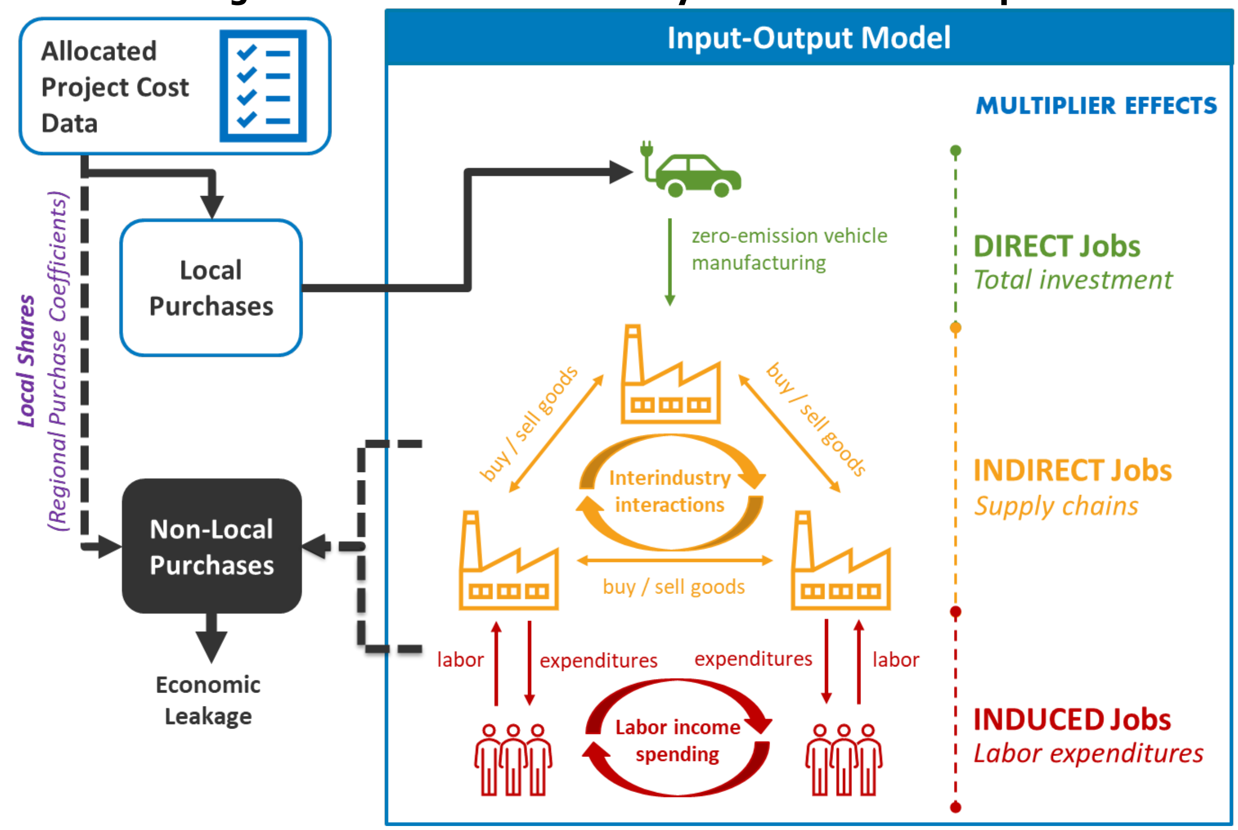
Figure 20: Distribution of Investments Among Sectors, All Years



Source: NREL

An important assumption required in this analysis is who is supplying the equipment, materials, and services for these particular projects: whether in-state or out-of-state businesses. The more that is locally purchased, the more in-state jobs will be supported by a particular project, and less "economic leakage" to other states/foreign countries will occur. Economic leakage occurs when goods and services required by the projects are provided by companies outside California (non-local purchases), and therefore do not generate local impacts. Given the disaggregation of the model, in this analysis IMPLAN's default regional purchase coefficients are applied, which represent the percentage of local purchases for each good/service from California businesses across the entire state (regional purchase coefficients vary by commodity and year due to the evolving regional economic structure). This is the same assumption employed in the 2021 report. The amount of California purchases is then used to introduce a demand shock in the model and to determine the total economic impact including jobs created in the state due to these investments. Figure 21 shows the model workflow. In this report, contemporaneous models from 2013 to 2022 (most recent year available) are used. Since IMPLAN does not provide projected social accounting matrix tables for the period between 2023 and 2028, the 2022 table is used to estimate job impacts for those years. To keep consistency in the databases across all the analyzed years, 2022's prices are used. Occupational information, including types of occupations, average wages, and education, experience, and training requirements, are based on IMPLAN's 2019 occupational dataset.

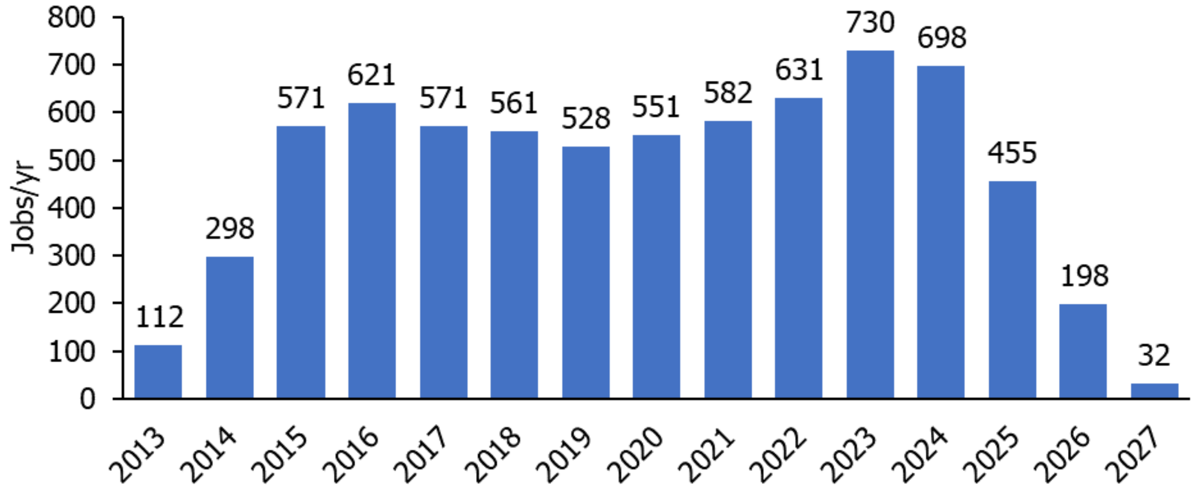
Figure 21: IMPLAN's Job Analysis Workflow Example



Source: NREL

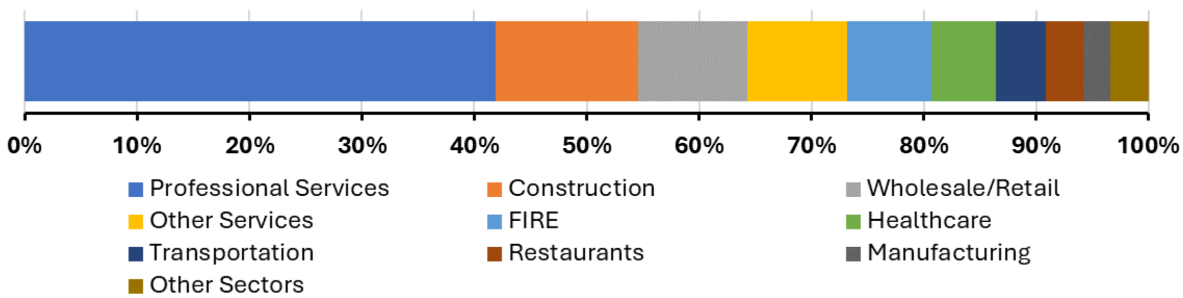
Figure 22 shows the estimated jobs supported per year in California from CTP-funded projects. On average, during the main investment period from 2015 to 2025, around 590 wage and salary jobs are supported across the state, peaking at 730 jobs supported in 2023. Most of these jobs are in professional services, construction, and wholesale/retail sectors (Figure 23). This distribution is consistent up to 2023, with more jobs supported in professional services sectors in the later years. The latter industry shows the strongest response to CTP investments, supporting on average 240 jobs per year, around 38 percent of annual employment impacts. The construction sector follows, supporting an average of 80 jobs/year from 2013 to 2027 (11 percent of annual employment impacts), peaking at 172 jobs in 2022.

Figure 22: Total Wage and Salary Jobs Supported by Year, 2013–2027



Source: NREL

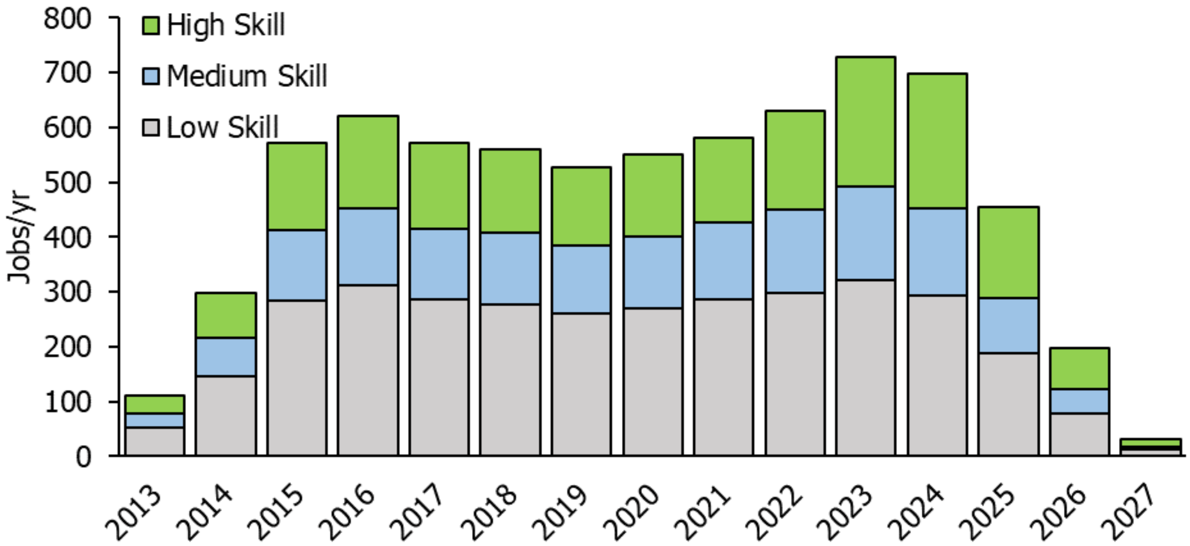
Figure 23: Distribution of Jobs Supported by Sector, 2023



Source: NREL

The average profile of jobs supported is shown for 2023, the year with the most investments. As shown in Figure 24, most occupations supported are low skilled (i.e., require a high school diploma or less), accounting for 47 percent of all jobs supported over the period. Almost one-fifth of jobs required no previous experience (Figure 25), with 44 percent requiring none or less than 1 year. Moreover, 69 percent require no or less than 6 months of on-the-job training. Overall, the distribution of salaries for the jobs supported by these projects is slightly higher than the profile for California, with most salaries clustered in the $60,000–$80,000/yr range (Figure 26). One-third of the jobs created were in service-related occupations; 20 percent in construction, installation, and transportation occupations; and 4 percent in manufacturing occupations (Table 7).

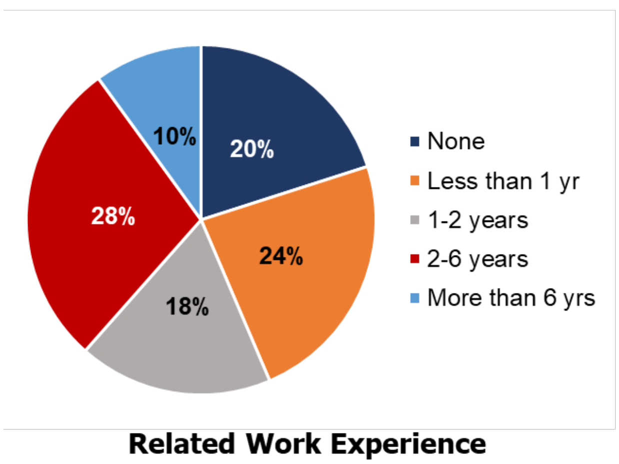
Figure 24: Total Employment by Skill Level per Year, 2013–2027

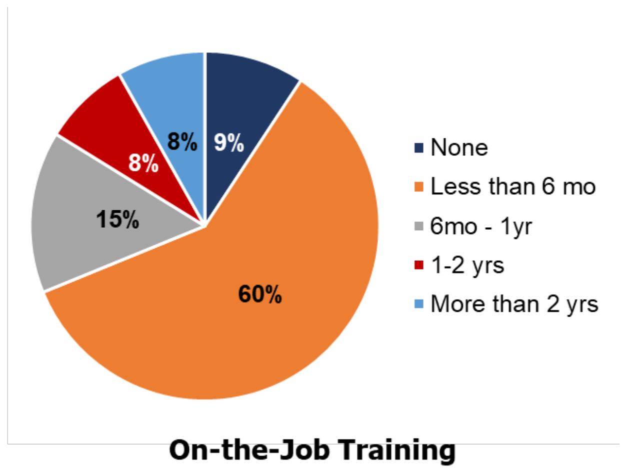


Source: NREL

Note: Low skill: high school diploma or less; medium skill: associate degree or less; high skill: bachelor's degree or more.

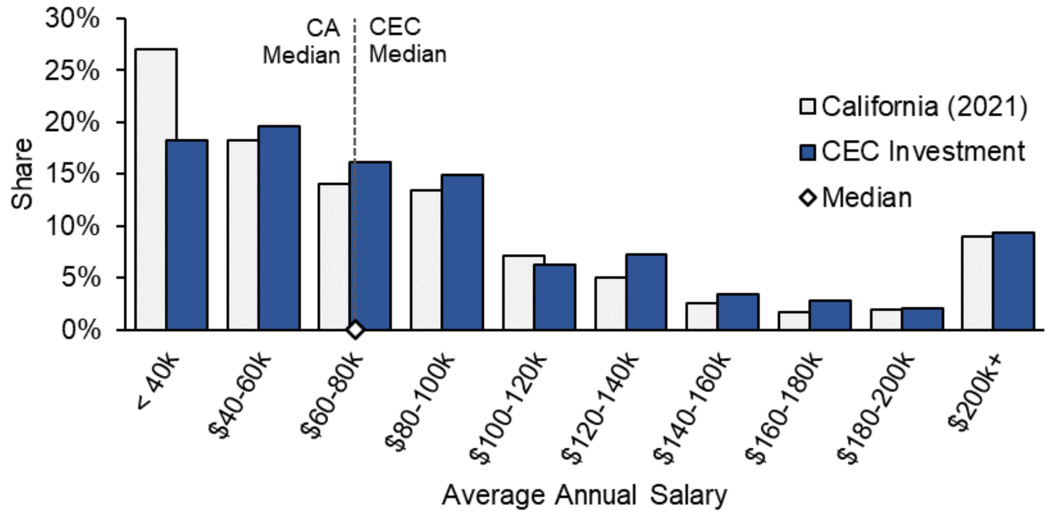
Figure 25: Distribution of Required Work Experience (left) and On-the-Job Training (right) for Jobs Supported in 2023





Source: NREL

Figure 26: Average Wage Distribution for Jobs Supported in 2021 (2021 dollars)



Source: NREL

Table 7: Share of Employment by Occupation, Jobs Created in 2023

Code	Occupation Group	Share
11-0000	Management Occupations	8%
13-0000	Business and Financial Operations Occupations	12%
15-0000	Computer and Mathematical Occupations	6%
17-0000	Architecture and Engineering Occupations	3%
19-0000	Life, Physical, and Social Science Occupations	2%
21-0000	Community and Social Service Occupations	1%
23-0000	Legal Occupations	1%
25-0000	Educational Instruction and Library Occupations	1%
27-0000	Arts, Design, Entertainment, Sports, and Media Occupations	2%
29-0000	Healthcare Practitioners and Technical Occupations	3%
31-0000	Healthcare Support Occupations	3%
33-0000	Protective Service Occupations	1%
35-0000	Food Preparation and Serving Related Occupations	7%
37-0000	Building and Grounds Cleaning and Maintenance Occupations	2%
39-0000	Personal Care and Service Occupations	1%
41-0000	Sales and Related Occupations	10%
43-0000	Office and Administrative Support Occupations	15%

Code	Occupation Group	Share
45-0000	Farming, Fishing, and Forestry Occupations	0%
47-0000	Construction and Extraction Occupations	8%
49-0000	Installation, Maintenance, and Repair Occupations	4%
51-0000	Production Occupations	4%
53-0000	Transportation and Material Moving Occupations	8%
99-0000	Military	0%

Source: NREL

It is important to note that our estimates should be interpreted within the context of the assumptions employed in the modeling, as well as the limitations of the input–output framework. The input–output model employed for this analysis is a static model (representing the economywide linkages and spending patterns in a given year). The model does not account for dynamic impacts or changes over time. As such, the aforementioned results do not account for changes in the economic structure (including electricity grid) over time—i.e., there are no economies of scale or technology changes in any industry. Moreover, the estimates are based on several assumptions about material sourcing.

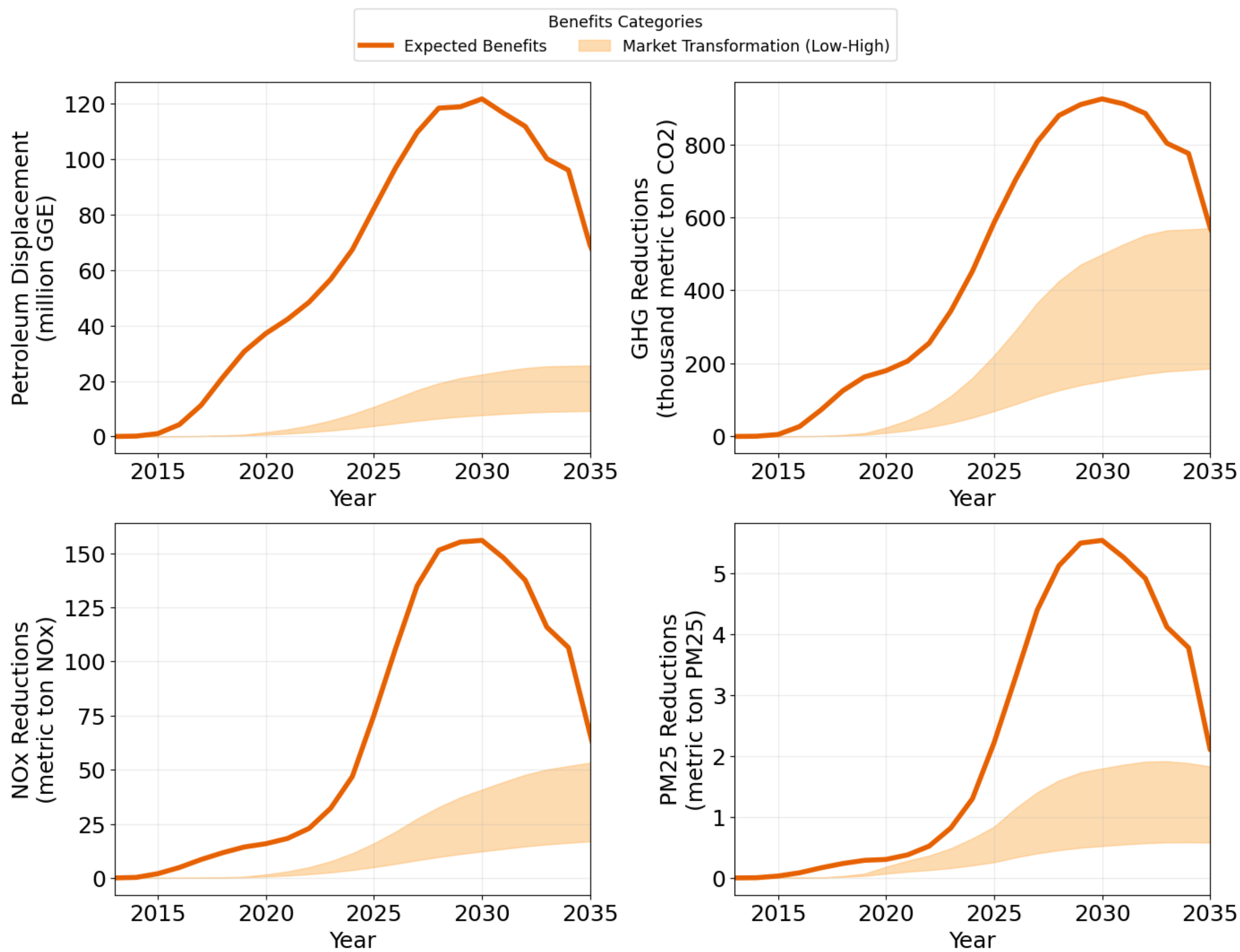
CHAPTER 5: Conclusion

This report evaluates the environmental and socioeconomic impact of projects funded by the CTP between 2013 and 2023. In total, 976 projects were included in the analysis for more than $1.04 billion in funding, of which $565 million was allocated to fueling infrastructure projects, $383 million to vehicle projects, and $88 million to fuel production. The categories of benefits in the report include expected benefits, which are direct results of CTP-funded projects; market transformation benefits, which are the product of the influence of CTP-funded projects on California's market for alternative vehicles; and economic benefits, which represent the broader impacts of these projects on California's economy in terms of job creation and wages.

Figure 27 summarizes the expected benefits and market transformation benefits associated with CTP-funded projects analyzed in this report. CTP-funded projects are estimated to provide significant environmental benefits. GHG emissions reductions, NO_x emissions reductions, and $PM_{2.5}$ emissions reductions for projects funded through 2023 all rise significantly from 2013 through 2030 before falling through 2035. Nearly 1 million metric tons of CO_2e are reduced annually by 2030, 350 percent above 2021 levels. The cumulative emissions reductions associated with CTP-funded projects from 2021 to 2030 account for nearly 5 percent of transportation GHGs emitted in California in 2021.[32] Market transformations resulting from CTP-funded projects could reduce GHG emissions by 165,260–522,190 metric tons of CO_2e annually in addition to the expected benefits by 2030. Air quality benefits are only estimated for fueling infrastructure and vehicle projects. CTP-funded projects are estimated to reduce NO_x emissions by 156 metric tons per year in 2030 and $PM_{2.5}$ emissions by 5.5 metric tons per year in 2030. Market transformations could provide up to 2 and 40 additional metric tons of $PM_{2.5}$ and NO_x emissions reductions, respectively, per year.

[32] CARB. 2023. "Current California GHG Emission Inventory Data: 2000-2021 GHG Inventory (2023 Edition)." Available at https://ww2.arb.ca.gov/ghg-inventory-data.

Figure 27: Summary of Expected Benefits and Market Transformation Benefits Associated With CTP Projects



In the expected benefits analysis, projects are assigned to census tracts, and results are presented in terms of the share of benefits realized in disadvantaged or low-income communities. This analysis can only be performed on a subset of projects in which geospatial attributes are available. In all years, across all four benefits categories, and of the projects with geospatial attributes, the majority of expected benefits occur in disadvantaged or low-income communities. A key outcome of the expected benefits analysis is that 78 percent of NO_x and $PM_{2.5}$ emissions reductions from projects with geospatial data are attributable to disadvantaged or low-income communities by 2030.

Based on the IMPLAN-estimated economic impact, the $1.04 billion (2022 dollars) of CTP-funded projects in California result in around 590 wage and salary jobs per year supported across the state. Most occupations are expected to be in professional services, construction, and wholesale/retail sectors. One-third of the jobs created are in service-related occupations; 20 percent in construction, installation, and transportation occupations; and 4 percent in manufacturing occupations. CEC investments mostly increase job opportunities for low-skilled workers with less than a year of prior work experience.

REFERENCES

California Air Resouces Board (CARB). 2006. "Title 17 Chapter 1 Subchapter 10 Article 4 Subarticle 7 Low Carbon Fuel Standard." California Code of Regulations Final Regulation Order, 128.

———. 2021. *2021 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development*. Sacramento, California. Available at https://ww2.arb.ca.gov/sites/default/files/2021-09/2021_AB-8_FINAL.pdf.

———. 2021. *EMFAC2021 Volume I – User's Guide*. Sacramento, California. Available at https://ww2.arb.ca.gov/sites/default/files/2021-01/EMFAC202x_Users_Guide_01112021_final.pdf.

———. 2023. "Current California GHG Emission Inventory Data: 2000-2021 GHG Inventory (2023 Edition)." Available at https://ww2.arb.ca.gov/ghg-inventory-data.

———. 2023. "EMFAC." Available at https://arb.ca.gov/emfac/.

———. 2023. "LCFS Life Cycle Analysis Model and Documentation." Available at https://ww2.arb.ca.gov/resources/documents/lcfs-life-cycle-analysis-models-and-documentation.

———. 2023. "LCFS Pathway Certified Carbon Intensities." Available at https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/fuelpathways/current-pathways_all.xlsx.

———. 2023. "Low Cabon Fuel Standard." Accessed November 2023. Available at https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard.

———. 2023. "Low Carbon Fuel Standard Reporting Tool Quarterly Summaries." Available at https://ww2.arb.ca.gov/sites/default/files/2023-10/quarterlysummary_Q22023.xlsx.

California Energy Commission. 2023. "Zero Emission Vehicle and Infrastructure Statistics." Data last updated Dec. 5th, 2023. Available at https://www.energy.ca.gov/zevstats.

Davis, Adam, Tiffany Hoang, Thanh Lopez, Jeffrey Lu, Taylor Nguyen, Bob Nolty, Larry Rillera, Dustin Schell, and Micah Wofford. 2023. *Second Assembly Bill (AB) 2127 Electric Vehicle Charging Infrastructure Assessment: Assessing Charging Needs to Support Zero-Emission Vehicles in 2030 and 2035*. California Energy Commission. Publication number CEC-600-2023-048. Available at https://www.energy.ca.gov/publications/2023/second-assembly-bill-ab-2127-electric-vehicle-charging-infrastructure-assessment.

Federal Highway Administration. 2019. "2019 National Household Travel Survey." Washington, D.C.: U.S. Department of Transportation. Available at https://nhts.ornl.gov.

Greene, D. 2001. *TAFV Alternative Fuels and Vehicles Choice Model Documentation.* Oak Ridge, Tennessee: Oak Ridge National Laboratory.

Greene, David L., Matteo Muratori, Eleftheria Kontou, Brennan Borlaug, Marc Melaina, and Aaron Brooker (NREL). 2020. *Quantifying the Tangible Value of Public Electric Vehicle Charging Infrastructure*. California Energy Commission. Publication Number: CEC-600-2020-004.

James, B., J. Huya-Kouadio, C. Houchins, and D. DeSantis. 2017. *Mass Production Cost Estimation of Direct H_2 PEM Fuel Cell Systems for Transportation Applications: 2016 Update*. Strategic Analysis Inc.: Arlington, Virginia.

———. 2018. *Mass Production Cost Estimation of Direct H_2 PEM Fuel Cell Systems for Transportation Applications: 2018 Update*. Strategic Analysis Inc.: Arlington, Virginia.

Jeffers, M., K. Kelly, T. Lipman, A. Avelino, C. Johnson, M. Li, M. Post, and Y. Zhang. 2022. *Comprehensive Review of California's Innovative Clean Transit Regulation: Phase I Summary Report*. Golden, Colorado: NREL. NREL/TP-5400-83232. Available at https://www.nrel.gov/docs/fy23osti/83232.pdf.

Knehr, K., J. Kubal, P. Nelson, and S. Ahmed. 2022. *Battery Performance and Cost Modeling for Electric-Drive Vehicles: A Manual for BatPaC v5.0*. ANL/CSE-22/1. Argonne National Laboratory: Lemont, Illinois. Available at https://publications.anl.gov/anlpubs/2022/07/176234.pdf.

Melaina, M., E. Warner, Y. Sun, E. Newes, and A. Ragatz (NREL). 2014. *Program Benefits Guidance: Analysis of Benefits Associated with Projects and Technologies Supported by the Alternative and Renewable Fuel and Vehicle Technology Program*. California Energy Commission. Publication Number: CEC-600-2014-005-D.

Melaina, M., J. Bremson, and K. Solo. 2012. "Consumer Convenience and the Availability of Retail Stations as a Market Barrier for Alternative Fuel Vehicles." in *31st USAEE/IAEE North American Conference*, Austin, Texas. Available at https://www.nrel.gov/docs/fy13osti/56898.pdf.

Neuman, C., M. Gilleran, C. Hunter, R. Desai, and A. F. T. Avelino (NREL). 2021. *Analysis of Benefits Associated With Projects and Technologies Supported by the Clean Transportation Program*. California Energy Commission. Publication Number: CEC-600-2021-039.

NuStats Research Solutions. 2013. "2010-2012 California Household." California Department of Transportation.

U.S. Department of Energy. 2021. "Alternative Fuels Data Center." Accessed November 3rd, 2021. Available at https://www.afdc.energy.gov.

U.S. Department of Energy Office of Energy Efficiency & Renewable Energy. 2015. "Maps and Data - Average Annual Vehicle Miles Traveled by Major Vehicle Category." Available at https://www.afdc.energy.gov/data/10309.

U.S. Energy Information Administration. 2023. "Annual Energy Outlook 2023 With Projections to 2050." Available at https://www.eia.gov/outlooks/aeo/.

Wood, E., S. Raghavan, C. Rames, J. Eichman, and M. Melaina. 2017. *Regional Charging Infrastructure for Plug-In Electric Vehicles: A Case Study of Massachusetts*. Golden, CO: National Renewable Energy Laboratory. NREL/TP-5400-67436. Available at https://www.nrel.gov/docs/fy17osti/67436.pdf.

GLOSSARY

Battery-electric vehicle (BEV)	Also known as an "all-electric" vehicle, BEVs use energy stored in rechargeable battery packs. BEVs sustain power through the batteries and therefore must be plugged into an external electricity source to recharge.
California Air Resources Board (CARB)	The state's lead air quality agency consisting of an 11-member board appointed by the Governor and slightly more than a thousand employees. CARB is responsible for attainment and maintenance of the state and federal air quality standards, California climate change programs, and motor vehicle pollution control. It oversees county and regional air pollution management programs.
California Electric Vehicle Infrastructure Project (CALeVIP)	The California Electric Vehicle Infrastructure Project (CALeVIP) is a funding opportunity offered by the California Energy Commissions that provides funding for installing publicly accessible electric vehicle charging stations in California.
California Energy Commission (CEC)	The state agency established by the Warren-Alquist State Energy Resources Conservation and Development Act in 1974 (Public Resources Code, Sections 25000 et seq.) responsible for energy policy. The CEC's five major areas of responsibilities are: 1. Forecasting future statewide energy needs. 2. Licensing power plants sufficient to meet those needs. 3. Promoting energy conservation and efficiency measures. 4. Developing renewable and alternative energy resources, including helping develop clean transportation fuels. 5. Planning for and directing state response to energy emergencies. Funding for the CEC's activities comes from the Energy Resources Program Account,

	Federal Petroleum Violation Escrow Account, and other sources.
Carbon dioxide equivalent (CO_2e)	A metric used to compare emissions of various greenhouse gases. It is the mass of carbon dioxide that would produce the same estimated radiative forcing as a given mass of another greenhouse gas. Carbon dioxide equivalents are computed by multiplying the mass of the gas emitted by the associated global warming potential.
Carbon intensity (CI)	A life cycle carbon intensity (CI) measures the GHG emissions and is expressed in grams (g) of carbon dioxide equivalent (CO_2e) resulting from each megajoule (MJ) of energy delivered by a fuel. A lifecycle CI is typically estimated using a Life Cycle Analysis (LCA) which accounts for GHGs emitted in every stage of production and use of a fuel.
Clean Transportation Program (CTP)	The California Energy Commission's Clean Transportation Program (CTP) provides funding to support innovation and accelerate the development and deployment of advanced transportation and fuel technologies.
Clean Vehicle Rebate Project (CVRP)	CVRP promotes clean vehicle adoption in California by offering rebates of up to $7,000 for the purchase or lease of new, eligible zero-emission vehicles, including electric, plug-in hybrid electric, and fuel cell vehicles.
Direct-current fast charger (DCFC)	Direct-current fast charger (DCFC) equipment provides direct-current charging using 480 volt alternating current outlets.
Electric vehicle (EV)	An electric vehicle (EV) is a vehicle that can be powered by an electric motor and draws electricity from a battery.
Electric vehicle supply equipment (EVSE)	Infrastructure designed to supply power to EVs. EVSE can charge a wide variety of EVs, including BEVs and PHEVs.
EMission FACtor (EMFAC)	EMission FACtor (EMFAC) is a model developed by California Air Resources Board that estimates the official emissions inventories of onroad mobile sources in California.

Energy economy ratio (EER)	The energy economy ratio (EER) represents the efficiency of a fuel used in a powertrain compared to a reference fuel used in the same powertrain.
Fuel cell electric vehicle (FCEV)	A zero-emission vehicle that runs on compressed hydrogen fed into a fuel cell "stack" that produces electricity to power the vehicle.
Gasoline gallon equivalent (GGE)	The amount of alternative fuel it takes to equal the energy content of one liquid gallon of gasoline. GGE allows consumers to compare the energy content of competing fuels against a commonly known fuel — gasoline. GGE also compares gasoline to fuels sold as a gas (natural gas, propane, and hydrogen) and electricity.
Greenhouse gas (GHG)	Any gas that absorbs infrared radiation in the atmosphere. Greenhouse gases include water vapor, carbon dioxide (CO2), methane (CH4), nitrous oxide (NOx), halogenated fluorocarbons (HCFCs), ozone (O3), per fluorinated carbons (PFCs), and hydrofluorocarbons (HFCs).
Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP)	California's Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project (HVIP), part of California Climate Investments, was created by California Air Resources Board in 2009 and provides point-of-sale vouchers to make advanced vehicles more affordable.
Hydrogen refueling station (HRS)	A hydrogen refueling station (HRS) is an infrastructure designed for filling a vehicle with hydrogen fuel. It can be part of a station for fossil fuel refueling or an independent infrastructure.
IMpact analysis for PLANning (IMPLAN)	IMpact Analysis for PLANning (IMPLAN) is a platform for input–output modeling that provides state-level data to estimate the total impacts of structural changes (new industries, sector growth, and demand shocks) in a given region in terms of local jobs, gross domestic product, labor income, industrial output, and taxes.
Level 2 (L2)	Level 2 (L2) equipment provides AC charging through 240V outlets for residential

	applications and 208V outlets for commercial applications.
Light duty (LD)	Light duty (LD) vehicles refer to compact cars, midsize cars, sport-utility vehicles (SUVs), and pickup trucks.
Low Carbon Fuel Standard (LCFS)	A set of standards designed to encourage the use of cleaner low-carbon fuels in California, encourage the production of those fuels, and, therefore, reduce greenhouse gas emissions. The LCFS standards are expressed in terms of the carbon intensity of gasoline and diesel fuel and the respective substitutes. The LCFS is a key part of a comprehensive set of programs in California that aim cut greenhouse gas emissions and other smog-forming and toxic air pollutants by improving vehicle technology, reducing fuel consumption, and increasing transportation mobility options.
Medium and heavy duty (MD/HD)	The California Energy Commission defines medium and heavy duty (MD/HD) vehicles as vehicles that have gross vehicle weight rating greater than 10,000 pounds and include vans, buses, and trucks.
National Renewable Energy Laboratory (NREL)	The United States' primary laboratory for renewable energy and energy efficiency research and development. NREL is the only federal laboratory dedicated to the research, development, commercialization, and deployment of renewable energy and energy efficiency technologies. Located in Golden, Colorado.
Nitrogen oxides (NO_x)	A general term pertaining to compounds of nitric oxide (NO), nitrogen dioxide (NO2), and other oxides of nitrogen. Nitrogen oxides are typically created during combustion and are major contributors to smog formation and acid deposition. NO2 is a criteria air pollutant and may result in numerous adverse health effects.
Particulate matter ($PM_{2.5}$)	Unburned fuel particles that form smoke or soot and stick to lung tissue when inhaled. A chief component of exhaust emissions from heavy-duty diesel engines.
Plug-in electric vehicle (PEV)	A general term for any car that runs at least partially on battery power and is recharged

	from the electricity grid. There are two types of PEVs to choose from — pure battery-electric and plug-in hybrid vehicles.
Plug-in hybrid electric vehicle (PHEV)	A PHEV is powered by an internal combustion engine and an electric motor that uses energy stored in a battery. The vehicle can be plugged in to an electric power source to charge the battery. Some can travel nearly 100 miles on electricity alone, and all can operate solely on gasoline.
Vehicle miles traveled (VMT)	The number of miles travelled by on-road vehicles.
Willingness to pay (WTP)	WTP is the amount of value that is derived from the investment in Plug-in Electric Vehicle charging infrastructure.
Zero-emission vehicle (ZEV)	A zero-emission vehicle (ZEV) is a vehicle with zero tailpipe greenhouse gas emissions and consist of battery-electric vehicles and fuel cell electric vehicles.

BIBLIOGRAPHY

Argonne National Laboratory. 2015. "CA-GREET 2.0 Model."

Brooker, A., J. Gonder, and S. Lopp. 2015. "ADOPT: A Historically Validated Light Duty Vehicle Consumer Choice Model." *SAE 2015 World Congress & Exhibition.* Detroit, Michigan: SAE International.

California Air Resouces Board (CARB). 2015. "LCFS Final Regulation Order, LCFS Compliance Schedule." Sacramento, California. Available at https://www.arb.ca.gov/regact/2015/lcfs2015/lcfsfinalregorder.pdf.

———. 2017. "CA-VISION 2.1 Scenario Modeling System."

———. 2019. 2019 Annual Evaluation of Fuel Cell Electric Vehicle Deployment & Hydrogen Fuel Station Network Development. Available at https://ww2.arb.ca.gov/sites/default/files/2019-07/AB8_report_2019_Final.pdf.

———. 2019. "California LCFS Data Dashboard." Available at https://www.arb.ca.gov/fuels/lcfs/dashboard/creditpricecalculator.xlsx.

Heo, J., P. J. Adams, and H. O. Gao. 2016. "Public health costs of primary $PM_{2.5}$ and inorganic $PM_{2.5}$ precursor emissions in the United States." *Environmental Science & Technology* 50 (11): 6061–6070. Available at https://doi.org/10.1021/acs.est.5b06125.

———. 2016. "Reduced-form modeling of public health impacts of inorganic $PM_{2.5}$ and precursor emissions." *Atmospheric Environment* 137: 80–89. Available at https://doi.org/10.1016/j.atmosenv.2016.04.026.

Lin, Z., and D.L. Greene. 2011. "Promoting the Market for Plug-in Hybrid and Battery Electric Vehicles: Role of Recharge Availability." *Transportation Research Record* 2252 (1): 49–58. Available at https://doi.org/10.3141/2252-07.

Millstein, D., R. Wiser, M. Bolinger, and G. Barbose. 2017. "The climate and air-quality benefits of wind and solar power in the United States." *Nature Energy* 2: 17134. Available at https://doi.org/10.1038/nenergy.2017.134.

National Research Council. 2013. *Transitions to Alternative Vehicles and Fuels.* Washington, D.C.: The National Academic Press.

U.S. Energy Information Administration. 2019. *Annual Energy Outlook 2019 with Projections to 2050.*

U.S. Environmental Protection Agency. 2019. "MOVES and Other Mobile Source Emissions Models." Available at https://www.epa.gov/moves.

APPENDIX A: Input Assumptions for Expected Benefits

This appendix details the assumptions and input parameters used to conduct the expected benefits analysis in Chapter 2. Table A-1 summarizes fuel economies for each vehicle type and fuel type in 2020, 2025, 2030, and 2035.

Table A-1: Assumed Fuel Economy by Vehicle and Fuel Type for Selected Years

Replaced Fuel	Vehicle Type	EMFAC Vehicle ID	Fuel Economy (miles/GGE)			
			2020	2025	2030	2035
Gasoline	LD car	LDA	33.15	39.88	39.8	39.85
Gasoline	LD truck	LDT1	28.67	37.79	37.73	37.77
Diesel	LD car	LDA	38.78	46.69	46.7	46.82
Diesel	Light/heavy duty	LHD1	21.19	21.2	21.24	21.26
Diesel	Urban bus	UBUS	4.16	4.16	4.16	4.16
Diesel	School bus	SBUS	6.73	6.73	6.73	6.71
Diesel	Other buses	OBUS	8.04	8.03	8.02	8.01
Diesel	Heavy-duty (>26,000 lbs)	T6 Instate Heavy	9.21	9.24	9.27	9.33
Diesel	Heavy-duty (<26,000 lbs)	T6 Instate Small	8.98	9.01	9.03	9.07
Diesel	Heavy-duty out-of-state	T6 OOS Heavy	9.26	9.3	9.34	9.39
Diesel	Heavy-duty California-registered truck	T7 CAIRP	6.96	7.02	7.06	7.08
Diesel	Drayage truck (other)	T7 Other Port	6.8	6.81	6.82	6.81
Diesel	Drayage truck (South Coast)	T7 POLA	6.59	6.63	6.67	6.68
Diesel	Solid waste collection truck	T7 SWCV	2.45	2.45	2.45	2.45
Diesel	Heavy-duty single-unit truck	T7 Single	6.97	6.98	6.98	6.99
Diesel	T7 single construction	T7 Single Construction	6.94	6.93	6.91	6.9
Diesel	Heavy-duty tractor	T7 Tractor	7.12	7.13	7.15	7.17

Source: EMFAC.

Table A-2 summarizes the NO_x emissions factors for each vehicle type and fuel type in 2020, 2025, 2030, and 2035.

Table A-2: Assumed NO_x Emissions Factor by Vehicle and Fuel Type for Selected Years

Replaced Fuel	Vehicle Type	EMFAC Vehicle ID	NO_x Emissions Factor (gNO_x/mile)			
			2020	2025	2030	2035
Gasoline	LD car	LDA	0.02	0.02	0.02	0.02
Gasoline	LD truck	LDT1	0.02	0.02	0.02	0.02
Diesel	LD car	LDA	0.02	0.01	0.01	0.01
Diesel	Light/heavy duty	LHD1	0.07	0.05	0.05	0.05
Diesel	Urban bus	UBUS	1.82	1.82	1.82	1.81
Diesel	School bus	SBUS	1.03	1.03	1.03	1.04
Diesel	Other buses	OBUS	0.43	0.43	0.44	0.44
Diesel	Heavy-duty (>26,000 lbs)	T6 Instate Heavy	0.86	0.85	0.81	0.78
Diesel	Heavy-duty (<26,000 lbs)	T6 Instate Small	0.81	0.82	0.81	0.80
Diesel	Heavy-duty out-of-state	T6 OOS Heavy	0.95	0.94	0.93	0.92
Diesel	Heavy-duty California-registered truck	T7 CAIRP	0.88	0.83	0.80	0.79
Diesel	Drayage truck (other)	T7 Other Port	0.99	0.95	0.95	0.97
Diesel	Drayage truck (South Coast)	T7 POLA	1.43	1.36	1.28	1.27
Diesel	Solid waste collection truck	T7 SWCV	1.89	1.89	1.89	1.89
Diesel	Heavy-duty single-unit truck	T7 Single	0.83	0.85	0.87	0.88
Diesel	T7 single construction	T7 Single Construction	0.89	0.93	0.98	1.00
Diesel	Heavy-duty tractor	T7 Tractor	0.85	0.85	0.83	0.81

Source: NREL

Table A-3 summarizes the $PM_{2.5}$ emissions factors for each vehicle type and fuel type in 2020, 2025, 2030, and 2035.

Table A-3: Assumed $PM_{2.5}$ Emissions Factors by Vehicle and Fuel Type for Selected Years

Replaced Fuel	Vehicle Type	EMFAC Vehicle ID	$PM_{2.5}$ Emissions Factor ($gPM_{2.5}$/mile)			
			2020	**2025**	**2030**	**2035**
Gasoline	LD car	LDA	0.02	0.02	0.02	0.02
Gasoline	LD truck	LDT1	0.02	0.02	0.02	0.02
Diesel	LD car	LDA	0.02	0.02	0.02	0.02
Diesel	Light/heavy duty	LHD1	0.04	0.04	0.04	0.04
Diesel	Urban bus	UBUS	0.37	0.37	0.37	0.37
Diesel	School bus	SBUS	0.32	0.32	0.32	0.32
Diesel	Other buses	OBUS	0.06	0.06	0.06	0.06
Diesel	Heavy-duty (>26,000 lbs)	T6 Instate Heavy	0.06	0.06	0.06	0.06
Diesel	Heavy-duty (<26,000 lbs)	T6 Instate Small	0.06	0.06	0.06	0.06
Diesel	Heavy-duty out-of-state	T6 OOS Heavy	0.06	0.06	0.06	0.06
Diesel	Heavy-duty California-registered truck	T7 CAIRP	0.04	0.04	0.04	0.04
Diesel	Drayage truck (other)	T7 Other Port	0.04	0.04	0.04	0.04
Diesel	Drayage truck (South Coast)	T7 POLA	0.04	0.04	0.04	0.04
Diesel	Solid waste collection truck	T7 SWCV	0.04	0.04	0.04	0.04
Diesel	Heavy-duty single-unit truck	T7 Single	0.04	0.04	0.04	0.04
Diesel	T7 single construction	T7 Single Construction	0.04	0.04	0.04	0.04
Diesel	Heavy-duty tractor	T7 Tractor	0.04	0.04	0.04	0.04

Source: NREL

Table A-4 lists the CI standards for gasoline and diesel fuels, as outlined in CARB's 2020 LCFS regulation.

Table A-4: California LCFS CI Target for Gasoline and Diesel Fuels

Year	Gasoline Standard (gCO_2e/MJ)*	Diesel Standard (gCO_2e/MJ)*
2011	95.61	94.47
2012	95.37	94.24
2013	97.96	97.05
2014	97.96	97.05
2015	97.96	97.05
2016	96.5	99.97
2017	95.02	98.44
2018	93.55	96.91
2019	93.23	94.17
2020	91.98	92.92
2021	90.74	91.66
2022	89.5	90.41
2023	88.25	89.15
2024	87.01	87.89
2025	85.77	86.64
2026	84.52	85.38
2027	83.28	84.13
2028	82.04	82.87
2029	80.8	81.62
2030	79.55	80.36
2031	79.55	80.36
2032	79.55	80.36
2033	79.55	80.36
2034	79.55	80.36
2035	79.55	80.36

Source: NREL

* CI targets are assumed to remain at 2030 levels through 2035.

Table A-5 lists the energy densities for each fuel type considered in this analysis. The energy densities are collected from CARB's 2020 LCFS regulation.

Table A-5: Energy Density by Fuel Type

Fuel	Unit	Energy Density
Gasoline blendstock (CARBOB)	(MJ/gal)	119.53
Reformulated gasoline (CaRFG)	(MJ/gal)	115.83
Diesel	(MJ/gal)	134.47
Pure methane	(MJ/ft^3)	102
Liquefied natural gas	(MJ/gal)	78.83
Compressed natural gas	(MJ/therm)	105.5
Electricity	(MJ/kWh)	3.6
Hydrogen	(MJ/kg)	120
Ethanol	(MJ/kg)	80.53
Biodiesel	(MJ/gal)	126.13
Renewable diesel	(MJ/gal)	129.65

Source: CARB

Table A-6 lists the EER for each fuel type and vehicle type considered in this analysis. The EERs are collected from CARB's 2020 LCFS regulation.

Table A-6: EER by Vehicle Type and Fuel Type

Fuel/Vehicle Combination	EER Value Relative to Displaced Fuel	Displaced Fuel
Gasoline (including 6% and 10% ethanol blends) used in gasoline vehicles or 85% ethanol/15% gasoline blends used in flexible-fuel vehicles	1	Gasoline
Compressed natural gas used in LD spark-ignited vehicles	1	Gasoline
Electricity used in a BEV or PHEV	3.4	Gasoline
Hydrogen used in an FCEV	2.7	Gasoline
Diesel fuel or biomass-based diesel blends used in a diesel vehicle	1	Diesel
Compressed or liquefied natural gas used in a heavy-duty compression-ignition engine	1	Diesel
Electricity used in a BEV or PHEV heavy-duty truck	5.0	Diesel
Electricity used in a BEV or PHEV heavy-duty bus	3.1	Diesel
Electricity used in a drayage truck	2.7	Diesel
Electricity used in a locomotive	3.3	Diesel
Hydrogen used in a heavy-duty FCEV	1.9	Diesel

Source: CARB

For refueling infrastructure projects, vehicle projects, and fuel production projects (where a CI was not provided), we assume a "default" CI based on the observed feedstock mix in California in 2022. The observed feedstock mix along with the associated default CIs are listed in Table A-7.

Table A-7: Assumed Default CIs

Fuel	Feedstock	Source	CI (gCO_2e/MJ)
Electricity	Grid average	CARB LCFS Current Certified Pathways (GREET 3.0)	81.42
Hydrogen	54% fossil natural gas, 44% renewable, 2% electrolysis	CARB LCFS Quarterly Summary	110.77
Compressed natural gas	Fossil compressed natural gas	CARB LCFS Lookup Table	79.21
Ethanol	83% corn, 12% biomass, 5% other	CARB LCFS Quarterly Summary	58.84
Fischer–Tropsch diesel	Municipal solid waste	CARB LCFS Current Certified Pathways (GREET 3.0)	14.78
Biodiesel	31% distiller's corn oil, 32% used cooking oil, 25% tallow, 12% soy/canola oil	CARB LCFS Quarterly Summary	28.5
Ethanol*	Sweet sorghum*	CARB LCFS Quarterly Summary	50.15
Compressed natural gas*	Food scraps*	CARB LCFS Quarterly Summary	−28.2

Source: CARB

*Used for projects where the feedstock is specified, but the CI is not.

Table A-8 provides the conversion factors used to convert fuel volume into fuel energy, measured in GGE.

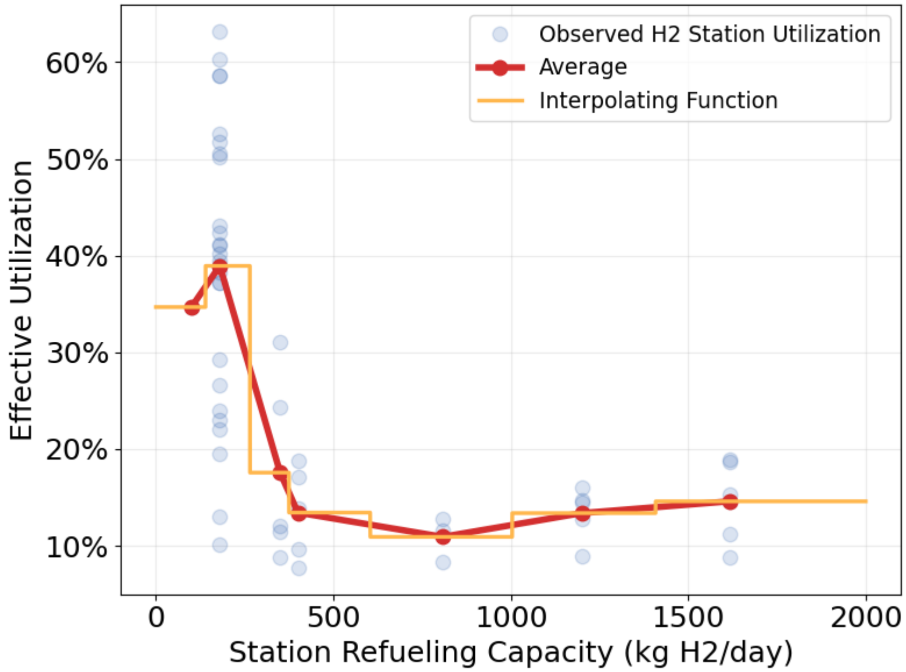
Table A-8: Energy Conversion Factors by Fuel Type

Fuel Type	Conversion Units	Conversion Factor
Gasoline	GGE/gallon	1.000
Diesel	GGE/gallon	1.115
Electricity	GGE/kWh	0.031
E85	GGE/gallon	0.734
Hydrogen	GGE/kg	1.019

Source: NREL

Figure A-1 shows the effective utilization recorded at CEC-funded HRSs as a function of station nameplate capacity. First, for stations with identical refueling capacity, the average is first calculated. Then, a piecewise constant interpolating function is fitted to the resulting data and used in Chapter 2 to estimate fuel throughput of individual HRSs based on their provided nameplate capacity.

Figure A-1: Recorded Utilization of CEC-Funded HRSs as a Function of Nameplate Refueling Capacity



Source: NREL

Table A-9 translates the assumed e-miles listed in Table 2 into annual utilization rates in percentage utilized per year.

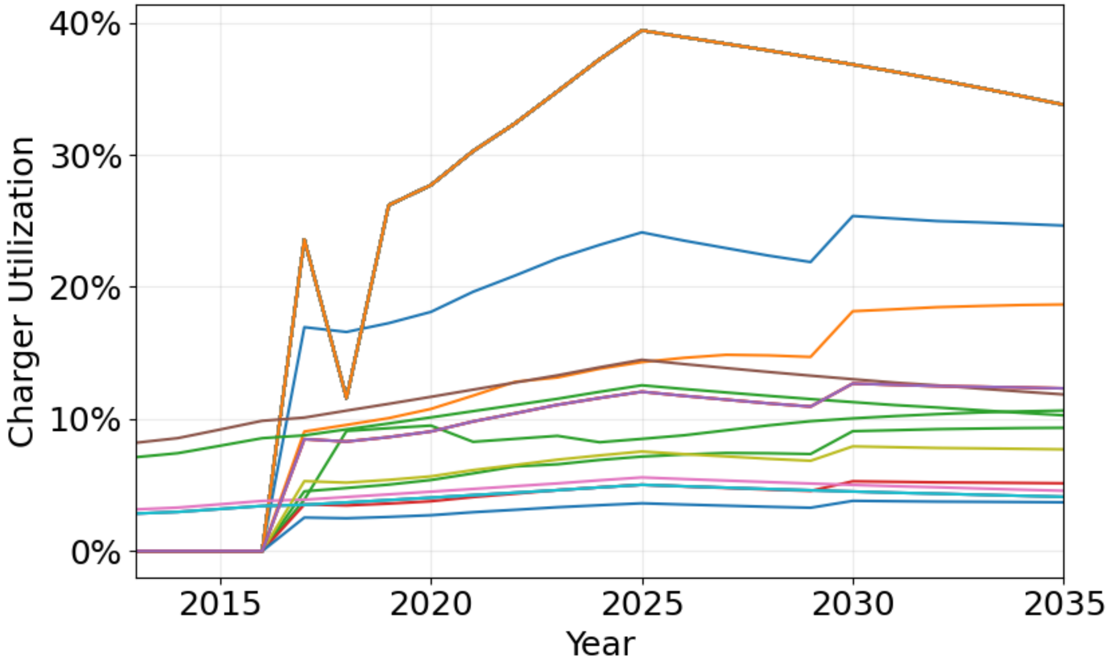
Table A-9: Implied Annual Utilization of Electric Chargers by Charger Type

Year	L2 Public	L2 Multifamily Home	L2 Workplace	DC 50 kW	DC 150 kW
2020	4.53%	4.53%	7.13%	6.12%	6.12%
2021	4.64%	6.38%	8.12%	6.89%	6.89%
2022	4.94%	8.46%	9.58%	7.76%	7.76%
2023	5.07%	10.23%	10.44%	8.63%	8.63%
2024	5.23%	12.01%	11.86%	9.50%	9.50%
2025	5.76%	14.66%	12.44%	10.37%	10.37%
2026	5.76%	14.66%	12.98%	11.24%	11.24%
2027	5.65%	14.40%	14.04%	12.11%	12.11%
2028	5.60%	14.27%	14.62%	12.98%	12.98%
2029	5.59%	14.25%	15.07%	13.85%	13.85%
2030	5.76%	14.66%	15.40%	14.72%	14.72%

Source: NREL

Figure A-2 shows charger utilization for MD/HD EVSE projects as estimated based on the VMT, number of vehicles, number of charging ports, and available charging power. Each line in the plot represents one of the 75 MD/HD EVSE projects included in the analysis.

Figure A-2: Annual Utilization of Chargers for MD/HD EVs



Source: NREL

Next, the process for determining the amount of funding and charging ports deployed for CALeVIP projects is described. The amount of funding and number of charging ports deployed were collected from the CALeVIP data dashboard on August 31, 2023. The CALeVIP program began in 2019. For the years 2019 through 2022, only projects listed as "completed" are included. For 2023, we include projects that have been completed and one-third of projects that are listed as "in-progress." For 2024 and 2025, one-third of in-progress projects are included for each year. The number of "in-progress" projects that are allocated to each year is the difference between the cumulative "in-progress" projects and completed projects in 2023 (to avoid double-counting). Table A-10 shows the resulting funding and number of connectors for DCFC and L2 connectors.

Table A-10: CALeVIP Project Funding and Number of Connectors by Type of Connector

Year	DCFC Funding	L2 Funding	DCFC Connectors	L2 Connectors
2019	$3,321,262	$611,600	100	164
2020	$10,252,399	$1,478,598	94	291
2021	$7,905,443	$3,771,346	410	464
2022	$7,416,825	$8,315,211	204	1,454
2023	$29,159,013	$28,312,827	733	2,817
2024	$23,786,279	$21,696,459	577	1,630
2025	$23,786,279	$21,696,459	577	1,630

Source: NREL

APPENDIX B: Input Assumptions for Market Transformation Analysis

Table B-1. Input Assumptions and Parameters in Determining the Change in PHEV, BEV, and FCEV Demand Due to Increase in Fueling Availability

Case	Weighted Price Change	Base Market Share	Demand Elasticity	P-Incumbent	P-New LD Vehicle	Price Slope
PHEVs				HEV	PHEV (with CVRP)	
Expected	−$211	10%	−5	$34,213	$38,513	−0.00016
Low	−$115	10%	−5	$34,213	$38,513	−0.00016
High	−$345	10%	−7	$34,213	$38,513	−0.00023
BEVs				PHEV Car	BEV car (with CVRP)	
Expected	−$160	10%	−5	$30,728	$38,602	−0.00018
Low	$0	10%	−5	$30,728	$38,602	−0.00018
High	−$326	10%	−7	$30,728	$38,602	−0.00025
FCEVs				PHEV	FCEV (with CVRP)	
High	−$530	10%	−8.88[33]	$35,717	$47,500	−0.00022
Low	−$530	2.5%	−5	$35,717	$62,500	−0.00014

Source: NREL

[33] This value deviates from others to align with the long-term expected sales by industry set in the *2021 Annual Evaluation of Fuel Cell Electric Vehicle Deployment and Hydrogen Fuel Station Network Development*.