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California Energy Commission

CONSULTANT REPORT

Analysis of Benefits Associated With Projects and Technologies Supported by the Clean Transportation Program

Prepared for: **California Energy Commission**

Prepared by: **National Renewable Energy Laboratory**

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California Energy Commission

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PREFACE

Assembly Bill 118 (Núñez, Chapter 750, Statutes of 2007) created the Clean Transportation Program (CTP), formerly known as the Alternative and Renewable Fuel and Vehicle Technology Program. The statute, subsequently amended by Assembly Bill 109 (Núñez, Chapter 313, Statutes of 2008), 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. AB 109 also requires the CEC to prepare a report on the expected benefits of program investments in reducing petroleum fuel use and carbon and criteria emissions from California’s transportation sector. Assembly Bill 8 (Perea, Chapter 401, Statutes of 2013) extends the expiration date of the Clean Transportation Program to January 1, 2024. The CEC has an annual program budget of about $100 million and provides financial support for projects that:

- Develop and improve alternative and renewable low-carbon fuels.
- Enhance alternative and renewable fuels for existing and developing engine technologies.
- Produce alternative and renewable low-carbon fuels in California.
- Decrease, on a full-fuel-cycle basis, the overall impact and carbon footprint of alternative and renewable fuels and increase sustainability.
- Expand fuel infrastructure, fueling stations, and equipment.
- Improve light-, medium-, and heavy-duty vehicle technologies.
- Retrofit medium- and heavy-duty on-road and non-road vehicle fleets.
- Expand infrastructure connected with existing fleets, public transit, and transportation corridors.
- Establish workforce training programs, conduct public education and promotion, and create technology centers.

ABSTRACT

The California Energy Commission’s Clean Transportation Program (CTP) supports a wide range of alternative, low-carbon fuel and vehicle projects. This report improves upon the *2014 Alternative and Renewable Fuel and Vehicle Technology Program (ARFVTP) Benefits Report*(the former name of 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 2014 and applies them for this 2021 Clean Transportation Program Benefits Report. The project team used data collected from CTP projects funded from 2009 to the third quarter of 2021 to estimate the benefits between 2021 and 2030. CTP projects valued at $898.3 million were assessed (out of $1.04 billion funded) to estimate expected benefits of 249 million gallons per year petroleum reduction and 2.79 million metric tons per year of carbon dioxide equivalent greenhouse gas (GHG) reduction in 2030. Market transformation benefits are additive to the expected benefits and were estimated with high and low ranges for the 315 relevant projects evaluated. The market transformation benefits’ GHG reductions are estimated as 2.2 million to 6.2 million metric tons of carbon dioxide equivalent per year and the petroleum reductions as 145.3 million to 671.5 million gasoline gallon equivalents per year in 2030. Combining both benefit types, the CTP projects can make significant progress toward meeting California’s long-term GHG and petroleum fuel use reduction goals.

Keywords: National Renewable Energy Laboratory, program benefits, alternative fuels, advanced vehicles, greenhouse gas emissions, criteria emissions, petroleum reduction

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TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

This report updates and expands upon the 2014 Alternative and Renewable Fuel and Vehicle Technology Program (renamed the Clean Transportation Program, CTP) Benefits Report developed by the California Energy Commission (CEC) and the National Renewable Energy Laboratory (NREL). The project team used the updated method documented in this report to assess the CTP benefits. Consistent with the original 2014 Benefits Report, this report focuses on benefits from two categories: expected benefits and market transformation benefits. The expected benefits are defined as benefits that accrue due to the direct displacement of petroleum-based fuels or vehicle technologies, while the market transformation benefits accrue due to CTP funding shifting the underlying market dynamics and accelerating the adoption of alternative fuel vehicles. In total, CTP investment has reached $1.04 billion since 2009. CEC staff provided sufficient data to evaluate $898.3 million (86 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.

The estimated benefits are segmented into two categories: expected benefits andmarket transformation benefits. Additionally NREL estimated the required carbon market growth trajectories.

The expected benefits represent the outcomes estimated to be directly supported by Clean Transportation Program funding. These benefits are based on the calculated displacement of petroleum-derived fuels for the vehicle, fuel, or infrastructure. To estimate GHG benefits, additional calculations consider the carbon intensity of a fuel. For example, the carbon intensity of biodiesel production depends in part on the feedstock input at a funded facility; similarly, the carbon intensity of an electric vehicle (EV) charger depends on the resource mix of the electricity grid in a given year. Air quality calculations consider baseline petroleum pollution emissions against the reduced pollutant profile of a replacement fuel. For example, hydrogen fuel used in light-duty fuel cell EVs have no oxides of nitrogen (NOx) or tailpipe particulate matter (PM) emissions compared to the petroleum it displaces. The project team-assessed market transformation effects cover a range of conditions underlying the inherent uncertainty with future market adoption rates. The market transformation benefits represent a range of future investments enabled or supported by the funding portfolio of the program. For example, the continuing market expansion of BEVs and PEVs will be partially supported by current Clean Transportation Program investments into electric charging infrastructure and the manufacture of battery and electric drivetrain technology. For electric chargers, charging availability is a leading consumer concern for vehicle adoption, so additional electric chargers contribute to changing consumer perceptions about the ease of purchasing a PEV. Similarly, the effect of a successful demonstration of an advanced technology truck or novel fuel production process increases the likelihood of that technology achieving future commercial success.

Importantly, for expected benefits and market transformation benefits, the identified benefits are associated with a project that the CTP funds at any level, without regard to other funding. For example, California's Low Carbon Fuel Standard and the Federal Renewable Fuel Standard Program create large incentives to motivate biofuel projects; 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.

Lastly, the team estimated the required trajectory of greenhouse gas (GHG) reductions needed to meet the long-term GHG reduction goal of 80 percent below 1990 levels by 2050. Since the rate at which these benefits must be realized in the near term (through 2030) is uncertain, the authors completed a low and high estimate based on the California Air Resource Board's *Vision for Clean Air* study to reflect the combined effect of all statewide policies and initiatives to reduce GHG emissions in the transportation sector.

Table ES-1 and Table ES-2 summarize the expected benefits and market transformation benefits from CTP-funded projects. As seen in Table ES-1 and Table ES-2, estimated expected benefits result in petroleum reductions of 249 million gallons of gasoline or diesel gallon equivalents per year in 2030, which in turn result in GHG reductions of 2.8 million metric tons of carbon dioxide equivalent per year. The market transformation and required carbon market growth benefits are also summarized in Table ES-1 and Table ES-2. Market transformation benefits are estimated to achieve GHG reductions of 2.1 million to 6.2 million metric tons of carbon dioxide equivalent per year and 145 million to 671.5 million gasoline gallon equivalents (GGE) per year reduction in petroleum use in 2030.

Table ES-1: Summary of Petroleum Reduction Benefits

Benefit Category	**Petroleum Fuel Reductions** (million gallons)		
	2020	**2025**	**2030**
Expected Benefits			
Fueling Infrastructure	44.1	80.2	101.3
Vehicles	20.6	58.2	63.6
Fuel Production	32.1	83.4	84.1
TOTAL	96.8	221.9	249.0
Market Transformation Benefits			
High Case	232.1	595.9	671.5
Low Case	70.2	126	145.3

Source: NREL

Table ES-2: Summary of GHG Fuel Reduction Benefits

Benefit Category	**GHG Reductions** (thousand metric tons carbon dioxide equivalent)		
	2020	**2025**	**2030**
Expected Benefits			
Fueling Infrastructure	185.7	506.5	714.9
Vehicles	200.0	616.7	739.6
Fuel Production	302.5	1321.2	1338.3
TOTAL	688.2	2,444.4	2,792.9
Market Transformation Benefits			
High Case	1,897.6	5,308.4	6,230.6
Low Case	806.3	1,804.4	2,182.4

Source: NREL

Table ES-3, Table ES-4, and Table ES-5 break down the expected benefits and market transformation benefits into the associated project categories. Again, the market transformation benefits include a low and high range because of the inherent uncertainty with future technology adoption rates. Overall, this analysis expands and improves upon past CTP benefit estimate efforts. However, this analysis could be improved by continuing to increase the input project data quality and also by modeling competitive dynamics between advanced and incumbent technologies.

Table ES-3: Petroleum Reductions (in million gallons) from Expected Benefits Through 2030

Project Class	Project Subclass	2020	2025	2030
Fuel Production	Biomethane	1.64	11.58	11.97
Fuel Production	Diesel Substitutes	25.0	59.4	59.4
Fuel Production	Gasoline Substitutes	5.48	12.88	13.19
Refueling Infrastructure	Biodiesel	6.43	6.43	6.43
Refueling Infrastructure	E85 Ethanol	5.89	5.99	5.99
Refueling Infrastructure	Electric Chargers	3.52	29.43	49.00
Refueling Infrastructure	Hydrogen	2.80	20.05	28.63
Refueling Infrastructure	Natural and Renewable Natural Gas	24.50	25.47	25.47
Vehicles	CVRP and HVIP Support	1.847	1.35	0.60
Vehicles	Demonstration	0.93	1.489	0.981
Vehicles	LPG Commercial Trucks	0.22	0.187	0
Vehicles	Light Duty BEVs and PHEVs	0.022	0.047	0.022
Vehicles	Manufacturing	15.52	51.595	60.014
Vehicles	NG Commercial Trucks	3.89	4.721	1.95
Total		97.7	230.68	263.76

Source: NREL

Table ES-4: GHG Reductions (in thousand metric tons) from Expected Benefits Through 2030

Project Class	Project Subclass	2020	2025	2030
Fuel Production	Biomethane	25.54	250.77	264.43
Fuel Production	Diesel Substitutes	258.75	963.98	964.04
Fuel Production	Gasoline Substitutes	18.18	99.38	102.8
Refueling Infrastructure	Biodiesel	23.97	23.97	23.97
Refueling Infrastructure	E85 Ethanol	17.82	18.13	18.13
Refueling Infrastructure	Electric Chargers	33.28	285.24	499.0
Refueling Infrastructure	Hydrogen	21.46	166.1	237.24
Refueling Infrastructure	Natural and Renewable Natural Gas	86.17	88.85	88.85
Vehicles	CVRP and HVIP Support	18.08	13.61	6.71
Vehicles	Demonstration	7.9	11.99	8.8
Vehicles	LPG Commercial Trucks	0.55	0.469	0
Vehicles	Light Duty BEVs and PHEVs	0.21	0.45	0.22
Vehicles	Manufacturing	169.95	587.575	723.86
Vehicles	NG Commercial Trucks	4.03	3.15	-0.074
Total		685.96	2513.73	2938.12

Source: NREL

Table ES-5: Petroleum and GHG Reductions from Market Transformation Benefits Through 2030

Market Transformation Influence	**Case**	**Petroleum Reductions** (million gasoline gallon equivalents/diesel gallon equivalents)			**GHG Reductions** (thousand metric tons carbon dioxide equivalent)		
		2020	**2025**	**2030**	**2020**	**2025**	**2030**
Fuel Production	High	62.1	167.8	169.2	275.3	1217.4	1234.5
	Low	15.5	41.9	42.3	68.8	304.4	308.6
Next Gen Trucks	High	63.1	247.4	290.8	313.1	1454.4	1825.7
	Low	3.7	14.8	19	25.5	133.8	185.1
Perceived Vehicle Price Reductions	High	16.1	49	65.3	184.2	585.7	803
	Low	7.2	19.4	24.3	82.1	230.3	296.1
Vehicle Cost Reduction	High	90.8	131.7	146.2	1125	2050.9	2367.4
	Low	43.8	49.9	59.7	629.9	1135.9	1392.6
Total	**High**	3872.8	10674.9	13000.1	3706.2	9784.1	11514.8
	Low	3854.5	10557	12890.6	3430.9	9702.6	11672.9

Source: NREL

CHAPTER 1: Introduction

This report updates the input data, calculation methodologies, and resulting outputs from the California Energy Commission's (CEC) 2014 Alternative and Renewable Fuel and Vehicle Technology Program Benefits Report.[1] These updated methods were used in a 2017 Alternative and Renewable Fuel and Vehicle Technology Program benefits analysis, the results of which were used internally by the CEC.[2] This report documents those updated methods as well.

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, large 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 the 2014 Benefits Report. As of October 2021, there are over 69,396 public and shared level 1 and level 2 chargers, and 6,776 DCFC (Direct-current fast charger) chargers supporting 980,225 plug-in electric vehicles (BEVs/PHEVs)[3] and 52 hydrogen refueling stations open supporting over 7,993 fuel-cell electric vehicles (FCEVs) in California.[4] These numbers

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[1] Melaina, M., E. Warner, Y. Sun, E. Newes and A. Ragatz. (NREL). 2013. *Program Benefits Guidance: Analysis of Benefits Associated With Projects and Technologies Supported by the Alternative and Renewable Fuel and Vehicle Technology Program.*

[2] The California Energy Commission and the National Renewable Energy Laboratory updated the 2014 Benefits Report methods to calculate benefits in 2017. These results were used in the CEC's *2017 Integrated Energy Policy Report* (https://efiling.energy.ca.gov/getdocument.aspx?tn=223205) as well as its *2018-2019 Investment Plan Update for the Alternative and Renewable Fuel and Vehicle Technology Program* (https://efiling.energy.ca.gov/getdocument.aspx?tn=223279).

[3] California Energy Commission (2021). California Energy Commission Zero Emission Vehicle and Infrastructure Statistics. Data last updated October 29, 2021. Retrieved November 3, 2021 from https://www.energy.ca.gov/zevstats

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

are in contrast to the 5,150 charge points supporting 118,250 PEVs and six hydrogen refueling stations supporting 125 FCEVs in 2014.[5]

This strong market growth results in direct environmental benefits, including greenhouse gas (GHG) emission 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 the direct government financial support as well as reduced uncertainty in future market conditions that stimulates additional private investment. The Clean Transportation Program (CTP) has continued to make strategic investments in a broad portfolio of projects that support the developing alternative transportation technology markets. The benefits of these investments are reviewed in the sections below. As in the 2014 Benefits Report, Chapters 2, 3, and 4 review the expected benefits, market transformation benefits, and required carbon market growth, respectively. Lastly, Chapter 5 summarizes the results and recommendations to enhance the benefit estimation methods.

Benefit Categories and Estimation Method

This report breaks down the estimated benefits from the CTP-supported projects into baseline benefits, expected benefits, market transformation benefits, and required carbon growth benefits. These components are the same as in the 2014 Benefits Report, which describes the specific attributes in Section 1.4[6]. This update report follows the same general benefit framework and focuses on estimating the expected benefits and market transformation benefits as were done in 2014. However, the expected benefit calculation method has been improved, and Chapter 2 describes the differences. Table 1 below summarizes major benefit categories, estimation methods, and data types and sources taken from the 2014 Benefits Report, and they are updated to reflect changes to the expected benefit calculation method.[1]

Market transformation includes as reducing barriers or correcting market imperfections for technologies that would otherwise prove competitive in the market. Market transformation also considers technologies that may have a modest market potential in the near term but significant potential over the long term. For details on the differences between the two types of market transformations considered and the unique position of the CTP in influencing market transformation in sustainable transportation, please refer to the discussion in Section 1.1 of the 2014 Benefits Report.[1]

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[5] United States. Department of Energy, "Alternative Fuels Data Center," September 2019. Available: https://www.afdc.energy.gov. (Accessed September 2019.)

[6] https://efiling.energy.ca.gov/GetDocument.aspx?tn=73185&DocumentContentId=10106

Effectiveness Metrics and Technology Innovation Systems

As in 2014, the benefit estimation method used is not 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 by the uncertainty in future market outcomes and timescales. 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.[1]

Table 1: Major Benefit Categories, Estimation Methods, and Main Data Types and Sources

BENEFIT CATEGORY	ESTIMATION METHOD	DATA TYPES AND SOURCES
Baseline Benefits. Occurring without projects supported by the Clean Transportation Program.	State-level data reported by the United States Energy Information Administration on alternative fuel vehicles and use	Empirical data from the United States Energy Information Administration, CEC, Department of Motor Vehicles, Polk
Expected Benefits. Direct investments to increase units deployed or fuel production capacity installed.	Fuel displacement, GHG reductions, and nitrogen oxides (NOx)/particle matter (PM2.5) emissions reductions based upon Clean Transportation Program project-level data and projected use or demand	Empirical data from Clean Transportation Program projects; CA-Vision data, some theoretical data on future market trends and demand
Market Transformation Benefits. Influence on market conditions to accelerate the adoption of new technologies.	Theoretical, based upon a combination of project-level data and market dynamic assumptions.	Various types (see below)
Vehicle Price Reductions. Due to rebates or R&D investments	Change in future market share due to reduced unit price	Theoretical estimate of price reduction and subsequent market share change
Public & Workplace Electric Vehicle Supply Equipment (EVSE). Due to number of local public EVSE charge points	Change in future market share due to influence of increased local charge points	Theoretical estimate of perceived value of public EVSE availability and service rate; planned deployments by urban and connecting areas
Hydrogen Station Availability*.* Due to increased number of local hydrogen refueling stations	Change in future market share due to influence of increased station availability locally	Theoretical estimate of reduction in perceived vehicle cost; consumer preference survey results; planned units deployments
Required Carbon Market Growth . Market shares increasing to meet or approach state goals	Calculation of trends in efficiency, carbon intensity, and market share growth of advanced vehicles and renewable fuel technologies; VISION vehicle stock model	Theoretical data on future market trends required to approach GHG goals

Source: NREL

CHAPTER 2: Expected Benefits

As of 2021, the transportation sector is the largest contributor of carbon dioxide emissions and is projected to increase its share of total U.S. emissions.[7] 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 (NG) 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. This chapter focuses on a subset of total CTP projects for which sufficient data are available to estimate expected benefits with some degree of certainty.

From 2009 to August 31, 2021, the CTP invested $1.04 billion in a wide selection of clean transportation projects. As of August 31, 2021, sufficient data are available to estimate the expected benefits or market transformation benefits or both for projects receiving $898.3 million in funding, which account for 86 percent of the total funding allocated by the CTP since 2009. The project team calculated expected benefits for projects representing $808.2 million of the $898.3 million (89 percent). Market transformation benefits were calculated for $852.9 million in funded projects (94 percent of the $898.3 million) and are discussed in Chapter 3. The team evaluated projects for estimated benefits and market transformation benefits, which were considered additive. Table 2 summarizes the funding by project categorization and fuel class.

Methods and Analytic Approach

The research team constructed a workflow and multiple models in the Python coding language to estimate expected benefits in the form of reductions in petroleum use and corresponding GHG emissions. Projects supporting ZEVs (including plug-in hybrid electric vehicles, battery electric vehicles, and FCEVs) had additional expected benefits estimated for select air pollutants. The results reported in the 2014 Benefits Report are not directly comparable to the

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[7] EIA. 2019. "Annual Energy Outlook 2019 With Projections to 2050." U.S. Energy Information Agency, Washington, D.C.

estimated expected benefits presented in this paper due to improvements in calculation methods, updated input data, and new data sources. The results are presented through 2030.

Projects Analyzed

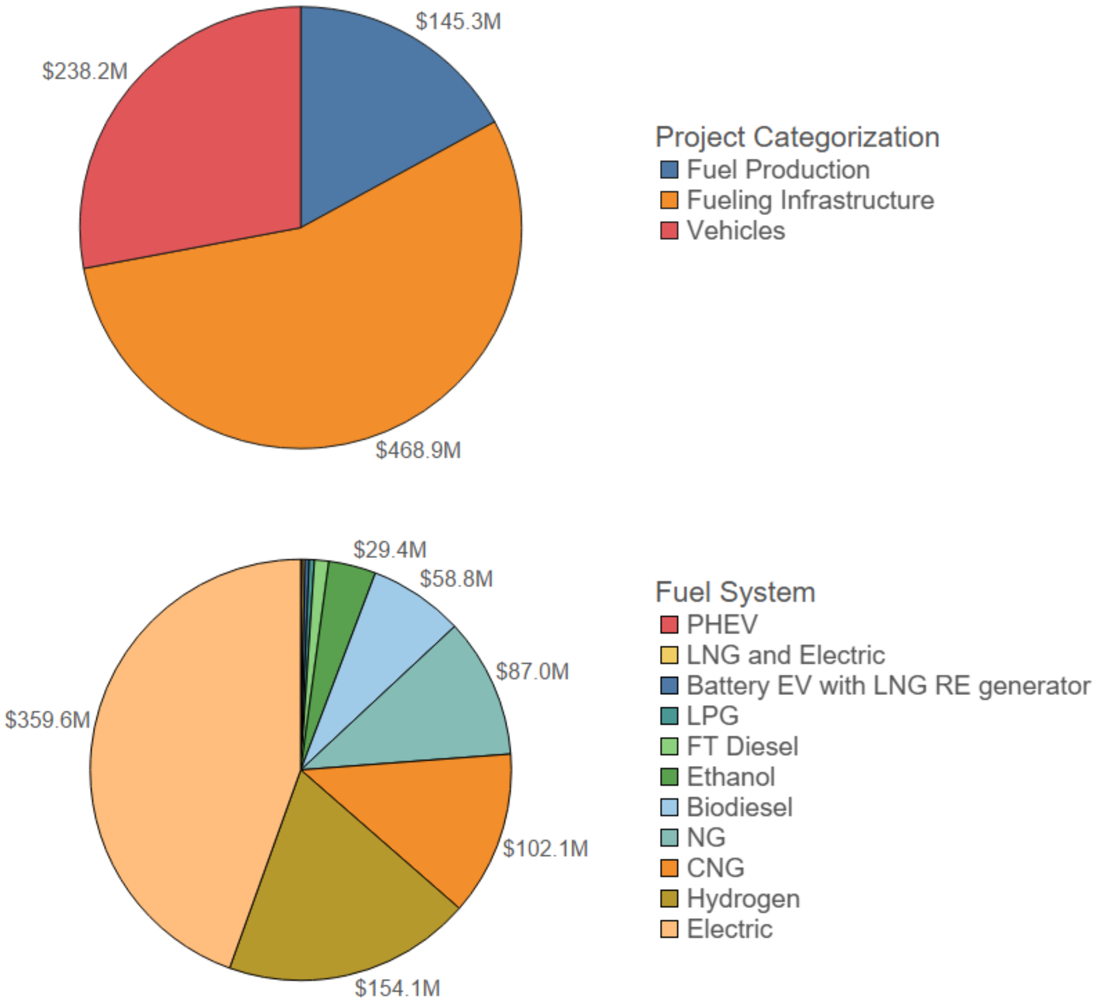
The CEC's Clean Transportation Program projects fall into three general categories: fueling infrastructure, vehicles, and fuel production, as shown in Table 2. The research team estimated the expected benefits for projects constituting $808.2 million of the $898.3 million invested. As noted above, various projects result in both expected benefits and market transformation benefits, which the project team considered additive for this analysis. Market transformation benefits are discussed in Chapter 3. Figure 1 summarizes the expected benefit estimates by project categorization and alternative fuel system.

Table 2: Clean Transportation Program Project Funding by Project Class

Project Class	Project Subclass	Funding (in millions)
Fuel Production	Biomethane	$65.4
Fuel Production	Diesel Substitutes	$56.8
Fuel Production	Gasoline Substitutes	$23.0
Fueling Infrastructure	Biodiesel	$2.0
Fueling Infrastructure	E85 Ethanol	$3.6
Fueling Infrastructure	Electric Chargers	$260.5
Fueling Infrastructure	Hydrogen	$137.0
Fueling Infrastructure	Natural and Renewable Gas	$21.5
Vehicles	CVRP and HVIP Support	$28.5
Vehicles	Demonstration	$119.1
Vehicles	Light Duty BEVs and PHEVs	$3.4
Vehicles	LPG Commercial Trucks	$3.1
Vehicles	NG Commercial Trucks	$84.1
Grand Total		$808.2

Source: CEC

Figure 1: Project Funding Breakdown by Project Categorization and Fuel System



Source: NREL

Model Construction

Consistent with the 2014 Benefits Report, the expected benefits model calculates the direct reduction of petroleum fuel consumption and emissions from using alternative fuels or driving advanced 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. As with the 2014 Benefits Report, the one exception is that life-cycle GHG emissions[8] and land-use related GHG emissions for select biofuels are estimated to parallel those of the California Air Resources Board's (CARB) Low Carbon Fuel Standard (LCFS).[9]

The model calculates expected benefits according to the project categorization. It begins by calculating petroleum fuel reductions. Based on petroleum fuel reductions, the model then calculates GHG emissions reductions and, in some cases, reductions in air pollution emissions. Model calculations are based on input data from the CEC staff, the CEC's Transportation Energy Forecast, life-cycle assessment models (GGHG, Regulated Emissions, and Energy Use in Transportation, CA-GREET)[10], and vehicle stock models (CA-VISION).[11]

Petroleum reduction calculations for fuel production projects, fueling infrastructure projects, and vehicles projects are calculated based on different methods. First, for fuel production projects, the model uses the 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 (DGE). 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 percentage of the year the project is expected to be operating to determine the petroleum fuel reductions for each year. To determine the percentage of year the project is operating (referred to as "percent year operation"), the model assumes that projects begin operation nine months before the contract end date and take three years for the project to linearly ramp up to full capacity. After the project has ramped up, the project team assumes that it operates at full capacity for the duration of the project life. This calculation method is the same as the 2014 Benefits Report.[1]

Fueling infrastructure projects have two calculation methods depending on whether it is an electric vehicle supply equipment (EVSE) project or not. For non-EVSE projects, petroleum reductions are based on the fuel throughput, the percent year operation, and the fuel's energy efficiency ratio. As in the fuel production calculations, the throughput values were provided in the CTP project descriptions, 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 "energy efficiency ratio" is the ratio of the new vehicle fuel economy to the displaced vehicle fuel economy to account for the new alternative fuel being used more efficiently than the displaced fuel. If the new vehicle fuel economy data are not available, the energy efficiency

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[8] California Air Resources Board (CARB). 2015. "LCFS Final Regulation Order, LCFS Compliance Schedule."

[9] California Air Resources Board (CARB). 2006. "Title 17 Chapter 1 Subchapter 10 Article 4 Subarticle 7 Low Carbon Fuel Standard."

[10] Argonne National Laboratory. 2015. "CA-GREET 2.0 Model."

[11] California Air Resources Board (CARB). 2017. "CA-VISION 2.1 Scenario Modeling System."

ratio is assumed constant over time and is taken from Table 3.[12] The petroleum reductions are calculated by multiplying the production throughput by the percent year operation and the energy efficiency ratio.

The petroleum reduction benefits from EVSE projects are based on the estimated number of miles (mi) provided by the charger (that is, miles that would not have been driven without the public charger, for example, only with home chargers), the fuel economy of a conventional gasoline vehicle, and the percent year operation. The number of additional miles provided by each type of EVSE is based on the EVI-Pro 2 model.[13] The EVI-Pro 2 model[14] uses travel data from the 2012 California Household Travel Survey[15] and the National Household Travel Survey[16] limited to the state of California. EVI-Pro 2 was used to determine the number and type of EVSE charging stations required to support California's electric vehicle (EV) adoption goals with respect to workplace and residential charging. The EVI-Pro 2 model estimates projected usage of charging stations by location and type. The electricity throughput (average kilowatt-hours/plug/year) is 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 electric vehicles efficiencies. Public charging e-miles estimates were generated using Alternative Fuels Database Center (AFDC) data in conjunction with actual measured California public charger usage data internal to NREL. Table 4 describes the average electricity throughput per charge point and the resulting estimated e-miles provided by each charge point on an annual basis.

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12 California Air Resources Board (CARB), September 2019. "California LCFS Data Dashboard." Available: https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard. Accessed September 2019.

13 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." National Renewable Energy Laboratory, https://www.nrel.gov/docs/fy17osti/67436.pdf.

14 The EVI-Pro model vintage of 2017 was used when estimating the Clean Transportation Program benefits in 2017. The same coefficients were used in this report as they were not expected to change significantly from 2017.

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

16 Federal Highway Administration. (2019). 2019 National Household Travel Survey, U.S. Department of Transportation, Washington, DC. Available online: https://nhts.ornl.gov.

Table 3: Energy Efficiency Ratio Values for Fuels Used in Light-, Medium-, and Heavy-Duty Applications

Fuel/Vehicle Combination	Energy Efficiency Ratio Values 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 Light-Duty Spark-Ignited Vehicles*	1	Gasoline
Electricity Used in a Battery-Electric or Plug-In Hybrid Electric Vehicle	3.4	Gasoline
Hydrogen Used in a Fuel Cell Vehicle	2.5	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 Battery-Electric (BEV) or Plug-In Hybrid Electric (PHEV) Heavy-Duty Truck	2.7	Diesel
Electricity Used in a BEV or PHEV Heavy-Duty Bus	4.2	Diesel
Hydrogen Used in a Heavy-Duty Fuel Cell Vehicle	1.9	Diesel

Source: NREL

Table 4: Average E-miles Enabled per Charge Point by Year

Year	Level 2 Public	Level 2 Multi-Family	Level 2 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
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

Lastly, vehicle projects' petroleum reductions were calculated using two approaches: one for nonmanufacturing projects and one for manufacturing projects. For both calculation methods, the project team assumed 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), the team used the vehicle-miles-traveled (VMT) and fuel economy of the replaced conventional vehicle 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.

The team took the data on the VMT and fuel economy by year and vehicle/fuel type from the CARB Vision 2.1 model. For all projects, the team assumed that there is a three-year ramp-up period. For nonmanufacturing vehicle projects, the team assumed that the model year of the new and conventional fuel (displaced) vehicles was the year associated with the project starting, nine months before the contract end date. In contrast, for manufacturing projects, the team tracked vehicle stock over time, and new conventional fuel vehicles were continually displaced each year by the new alternative vehicles that were manufactured in that year. Thus, the VMT and fuel economy used in the petroleum reduction calculations were based on the model year corresponding to the year of manufacture.

To use the CA-Vision 2.1 data on fuel economy and VMT, each of the vehicle projects must be matched to a vehicle type in the database. See Table in Appendix E for the CA-Vision 2.1

vehicle categories. Approximate matches based on vehicle weight and occupation were made to use the CA-Vision 2.1 data. Light-duty, medium-duty, and heavy-duty vehicle classification are determined by vehicle weight, Appendix D displays the CA-Vision 2.1 classes and definitions. Fueling infrastructure and fuel production projects were matched to vehicles based on the fuel class as described in Table 5.

Table 5: Fueling Infrastructure and Fuel Production Projects Match to Vehicles

Fuel Class	EMFAC Vehicle ID	Replaced Fuel
Biodiesel/Fischer–Tropsch Diesel/Renewable Diesel	T7 CAIRP	Diesel
Ethanol	Light-Duty Automobile	Gas
Natural Gas	OBUS	Diesel

Source: NREL

The CA-Vision 2.1 model does not contain data for all the vehicle, fuel, model year, and calendar year combinations needed to evaluate all the CTP projects. For example, project ARV-12-006 provides program funds to expand electric motorcycle production, yet the CA-Vision 2.1 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 project team then scaled the 2011 values to match the percentage changes in fuel economy and VMT observed for gasoline light-duty vehicles, as reported by the CA-Vision 2.1 model. Similarly, fuel economy and VMT for electric motorcycles were estimated by scaling the corresponding gasoline motorcycle value by the ratio of fuel economy and VMT of gasoline and electric light-duty vehicles.

Emission Reduction Factors

The project team used life-cycle GHG emissions of petroleum and alternative fuels to generate a set of GHG emission reduction factors. For most CTP fuel production projects (38 of 39), the information provided by CEC staff included an estimate of the carbon intensity of the alternative fuel. These values were used in calculating the project-specific emission reduction factors. For the fuel production project without a specified alternative fuel carbon intensity, the team used California's LCFS certified pathway carbon intensity for biodiesel from used cooking

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[17] U.S. Department of Energy Office of Energy Efficiency & Renewable Energy. June 2015. "Maps and Data - Average Annual Vehicle Miles Traveled of Major Vehicle Categories." Available: https://www.afdc.energy.gov/data/10309, accessed September 2017.

oil.[18] For the other CTP project classes (that is, vehicles and fueling infrastructure), the corresponding alternative fuel feedstocks are matched to carbon intensities based on LCFS certified pathway carbon intensities or, when not given by the LCFS fuels pathway table, the CA-GREET 2.0 model.[10] As in the 2014 Benefits Report, the team computed the emissions associated with additional electricity demand from EVs using the California marginal grid carbon intensity.

The team calculated the emission reduction factors based on the difference between the petroleum fuel carbon intensity (gasoline or diesel, depending on which is being displaced) and the alternative fuel carbon intensity adjusted by the energy efficiency ratio of the alternative fuel. The team applied CARB's energy efficiency ratios to the carbon intensity of the alternative fuel to account for the differences in energy efficiencies of alternative fuel vehicles and conventional vehicles. The energy efficiency ratios are ratios of the fuel economy of the alternative vehicles to petroleum-based vehicles, and thus the GHG emission reduction factors are calculated as: $CI_{\text{petroleum fuel}}$ - $CI_{\text{alternative fuel}}$/energy efficiency ratio and reported in grams (g) per mile driven. Table 3 from CARB lists the energy efficiency ratios relevant to this analysis.[12]

Table 6 describes the GHG emission factors by fuel system (including feedstock) description for projects without carbon intensities explicitly stated in the project descriptions. See Appendix F for the GHG emission factors associated with the fuel production projects with specified carbon intensities. Because there are different energy efficiency ratios associated with light-duty and heavy-duty vehicles, the GHG emission reduction factor differs across vehicle type even when the fuel feedstock is the same.

Air pollution reduction factors, similarly, in grams per mile driven, were applied to the VMT estimate associated with the fuel displacement calculations. These factors applied to vehicle and fueling infrastructure projects for electricity and hydrogen fuel types. The project team assumed that biofuel-based systems have the same tailpipe emissions as conventional fuels, consistent with the 2014 Benefits Report.

The air pollution data for conventional and alternative fuel vehicles were provided by the CARB Vision 2.1 model.[11] The CARB Vision 2.1 model describes air pollution emission factors that are a function of calendar year, age of vehicle, vehicle type, fuel type, and location. However, there are alternative vehicle-fuel-model year-calendar year combinations not included in the CA-Vision 2.1 model for which air pollution emissions are needed to evaluate all the CTP projects. These missing combinations are listed in Table 7 along with a brief explanation of how the emissions were estimated. Generally, the emissions of the missing vehicle-fuel combination were estimated by scaling the conventional vehicle emissions by the ratio of the alternative fuel and conventional fuel vehicle emissions using complete information in the CA-

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[18] California Air Resources Board (CARB). September 2017. "LCFS Pathway Certified Carbon Intensities." September 2017. Available: https://www.arb.ca.gov/fuels/lcfs/fuelpathways/pathwaytable.htm, accessed September 2017.

Vision 2.1 model. Only PM2.5 emissions were estimated for hydrogen and EVs (due to tire wear and tear), as they do not produce tailpipe oxides of nitrogen (NOx) emissions.

The project team estimated motorcycle emissions using light-duty vehicle emissions. Gasoline motorcycle PM2.5 emissions were assumed to be half of gasoline light-duty vehicle emissions, consistent with the estimation used by the Motor Vehicle Emissions Simulator.[19] Similarly, the PM2.5 emissions of electric motorcycles were assumed to be half that of electric light-duty vehicles. Unlike the PM2.5 emissions, which are from tire wear and tear, the NOx emissions for gasoline motorcycles are based on gasoline consumption per mile and estimated by scaling the gasoline light-duty vehicle NOx emissions factor by the ratio of the fuel efficiency of a gasoline motorcycle and a gasoline light-duty vehicle.

g NOx/mi [MC GAS] = g NOx/mi [Light-Duty Automobile GAS] * mi/gal [L Light-Duty Automobile DA GAS] / mi/gal [MC GAS]

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[19] U.S. Environmental Protection Agency (EPA). September 2019. "MOVES and Other Mobile Source Emissions Models." Available: https://www.epa.gov/moves.

Table 6: GHG Emission Reduction Factors Based on Fuel Feedstock and Energy Efficiency Ratio

Fuel	**Fuel System Description (for Light-Duty Vehicle)**	**Life Cycle Carbon Intensity (g Carbon Dioxide Equivalent/MJ)**	**GHG Emission Reduction Factor (g Carbon Dioxide Equivalent/MJ)**
Gasoline	AVG California Gasoline Blend	97	--
Diesel	AVG California Diesel	100	--
Light-Duty Vehicles			
Biodiesel	Used cooking oil (UCO) transesterification, where "cooking" is required	22	78
Biodiesel	90% UCO, 10% Soy	25	75
Biodiesel	50% Soy, 40% Corn, 10% UCO	42	58
CNG	California NG via pipeline; compressed in CA	80	20
CNG	Dairy digester Biogas to compressed natural gas	-273	373
CNG	90% NG, 10% Dairy Gas	45	55
CNG	75% NG, 25% Dairy Gas	-8	108
LNG	North American NG delivered via pipeline; liquefied in CA using liquefaction with 90% efficiency	90	10
LNG	Dairy digester Biogas to LNG liquefied in CA using liquefaction with 90% efficiency	18	82
LNG	70% LNG, 30% Dairy Biogas	69	31
Electric	CA marginal	106	65
Ethanol	California average; 80% Midwest Average; 20% California; Dry Mill; Wet DGS; NG	70	26
Ethanol	80% sugar beets, 20% forest residues	9	88
Fischer–Tropsch Diesel	Municipal solid waste Fischer–Tropsch Diesel	15	85

Fuel	Fuel System Description (for Light-Duty Vehicle)	Life Cycle Carbon Intensity (g Carbon Dioxide Equivalent/MJ)	GHG Emission Reduction Factor (g Carbon Dioxide Equivalent/MJ)
Hydrogen	compressed H2 from on-site reforming with renewable feedstocks	88	61
Hydrogen	23% NG, 77% Renewable	24	87
Hydrogen	66% NG, 33% Renewable	70	69
Medium- and Heavy-Duty Vehicles			
Electric	CA marginal – bus	106	75
Electric	CA marginal - HD truck	106	61
compressed natural gas	California NG via pipeline; compressed in CA – HD	80	20
LNG	North American NG delivered via pipeline; liquefied in CA using liquefaction with 90% efficiency – HD	90	10
Hydrogen	66% NG, 33% Renewable - HD	70	63
Hydrogen	23% NG, 77% Renewable - HD	24	87

Source: NREL

Table 7: Air Pollution Emission Factors for Clean Transportation Program Vehicles Not in CA-Vision 2.1 Model

Vehicle Type	Fuel	Model Years	Emissions Modeling Technique
MC	GAS	2011-2050	NOx estimated as emissions from Light-Duty Automobile GAS * FE ratio [Light-Duty Automobile /MC] PM2.5 estimated similarly to MOVES: 1/2 of emissions from Light-Duty Automobile ELE
MC	ELE	2011-2050	PM2.5 estimated similarly to MOVES: 1/2 of emissions from Light-Duty Automobile ELE
MDV	ELE	2015	Based on PM2.5 from MDV GAS * (Light-Duty Automobile ELE/ Light-Duty Automobile GAS)
OBUS	ELE	2017	Based on PM2.5 from OBUS GAS * (LDT2 ELE/LDT2 GAS)

Vehicle Type	Fuel	Model Years	Emissions Modeling Technique
SBUS	ELE	2018	Based on PM2.5 from SBUS GAS * (LDT2 ELE/LDT2 GAS)
T6 Instate Heavy	ELE	2016-2017	Based on PM2.5 from T6 Instate Heavy DSL * (LDT2 ELE/LDT2 DSL)
T6 Instate Small	ELE	2011-2019	Based on PM2.5 from T6 Instate Small DSL * (Light-Duty Automobile ELE/ Light-Duty Automobile DSL)
T6 Public	ELE	2011-2019	Based on T6 Public DSL * (Light-Duty Automobile ELE/ Light-Duty Automobile DSL)
T7 Other Port	ELE	2011-2032	Based on T7 Other Port DSL * (Light-Duty Automobile ELE/ Light-Duty Automobile DSL)
T7 Single Construction	ELE	2019	Based on PM2.5 from T7 Single Construction DSL * (LDT2 ELE/LDT2 DSL)
T7 SWCV	ELE	2017-2018	Based on PM2.5 from T7 SWCV DSL * (LDT2 ELE/LDT2 DSL)
T7 Tractor	ELE	2017-2020	Based on PM2.5 from T7 Tractor DSL * (LDT2 ELE/LDT2 DSL)
T7 Utility	ELE	2016	Based on PM2.5 from T7 Utility DSL * (LDT2 ELE/LDT2 DSL)
UBUS	ELE	2011-2050	Based on PM2.5 from UBUS GAS * (Light-Duty Automobile ELE/ Light-Duty Automobile GAS)
OBUS	HYD	2018	Based on PM2.5 from OBUS GAS * (LDT2 HYD/LDT2 GAS)
T6 Instate Small	HYD	2017	Based on PM2.5 from T6 Instate Small DSL * (Light-Duty Automobile ELE/ Light-Duty Automobile DSL)
T6 OOS Heavy	HYD	2018	Based on PM2.5 from T6 OOS Heavy DSL * (LDT2 HYD/LDT2 DSL)
T7 Other Port	HYD	2017	Based on PM2.5 from T7 Other Port DSL * (Light-Duty Automobile HYD/ Light-Duty Automobile DSL)
T7 Single	HYD	2018	Based on PM2.5 from T7 Single DSL * (LDT2 HYD/LDT2 DSL)
UBUS	HYD	2017-2018	Based on PM2.5 from UBUS GAS * (Light-Duty Automobile HYD/ Light-Duty Automobile GAS)
T6 Instate Small	PHEV	2015	Based on PM2.5 from T6 Instate Small ELE * (Light-Duty Automobile PHEV/ Light-Duty Automobile ELE)

Source: NREL

Because the operation of electric and hydrogen vehicles does not result in the production of any NOx emissions, the project team calculated the NOx reductions for these projects as the product of the VMT of the displaced vehicle, NOx emissions factor (in grams per mile), and number of vehicles. Electric and hydrogen vehicles, however, do have associated PM2.5

emissions. So PM2.5 emissions reductions were based on the difference between the conventional and alternative vehicle emission factors, as well as the VMT of the displaced vehicle and number of vehicles.

NOx_reduction [g NOx/yr] = old_vmt [mi/veh-yr] * number_vehicles [veh] * NOx_factor [g/mi] * pct_operation

PM2.5_reduction [g PM2.5/yr] = old_vmt [mi/veh-yr] * number_vehicles [veh] * (old_PM2.5_factor [g/mi] - new_PM2.5_factor [g/mi]) * pct_operation

For fueling infrastructure projects, the authors assumed that the displaced vehicle is a gasoline light-duty automobile. The NOx and PM2.5 emissions reductions were based on emissions factors for new vehicles. For example, to calculate the reductions in 2025, the authors assumed that the displaced vehicle emission factors were for a Model Year 2025 gasoline light-duty automobile, and the new PM2.5 emission factor was for a hydrogen or electric Model Year 2025 light-duty automobile. The NOx emissions reductions for hydrogen fueling infrastructure were calculated as the fuel production throughput [gge/year] multiplied by the new vehicle fuel economy [mi/gge], the displaced vehicle NOx emission factor [g NOx/mi], and the percent year operation. The new vehicle fuel economy is used to convert the throughput to miles displaced due to the fueling infrastructure (assuming a 1-to-1 displacement of EV mile to conventional vehicle mile). Mathematically, the NOx calculation is detailed in the equation below:

NOx_reduction [g NOx/yr] = throughput [gge/yr] * new_fuel_economy [mi/gge] * NOx_factor [g/mi] * pct_operation [percent]

The PM2.5 emissions reductions for hydrogen fueling infrastructure were calculated similarly but using the difference in the PM2.5 reduction factors:

PM2.5_reduction [g PM2.5/yr] = throughput [gge/yr] * new_fuel_economy [mi/gge] * (old_PM2.5_factor [g/mi] - new_PM2.5_factor [g/mi]) * pct_operation [percent]

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

NOx_reduction [g NOx/yr] = emiles [mi/yr] * NOx_factor [g/mi] * pct_operation [percent]

PM2.5_reduction [g PM2.5/yr] = emiles [mi/yr] * (old_PM2.5_factor [g/mi] - new_PM2.5_factor [g/mi]) * pct_operation

Scenarios

The target year for this report is 2030, where 2011–2030 were evaluated for the benefits analysis. Results for 2020, 2025, and 2030 are all consistently reported throughout the benefits analysis. As in the 2014 Benefits Report and the 2017 benefits analysis, the expected benefits were calculated for only one scenario with the highest probability rather than including potential high and low cases. In contrast, the market transformation calculations in Chapter 3 include multiple scenarios to provide a potential range in the benefits accrued because of fundamental market transformations.

As noted in the 2014 Benefits Report, this focus on one scenario for expected benefits does not imply absolute certainty in the benefits calculations. The expected benefit calculations include input data and assumptions projecting market changes over many decades, which will necessarily cause uncertainty in benefit estimations. Another uncertainty in the prediction of expected benefits exists because of the limited information on how vehicle fuel economy will evolve over time for various vehicle types. Since this information was unknown in some calculations, the authors used a constant energy efficiency ratio factor; yet the true value is expected to be dynamic based on vehicle technology improvements. Overall, these uncertainties are expected to be small relative to the absolute magnitude of the benefits calculated, so high and low cases were not estimated.

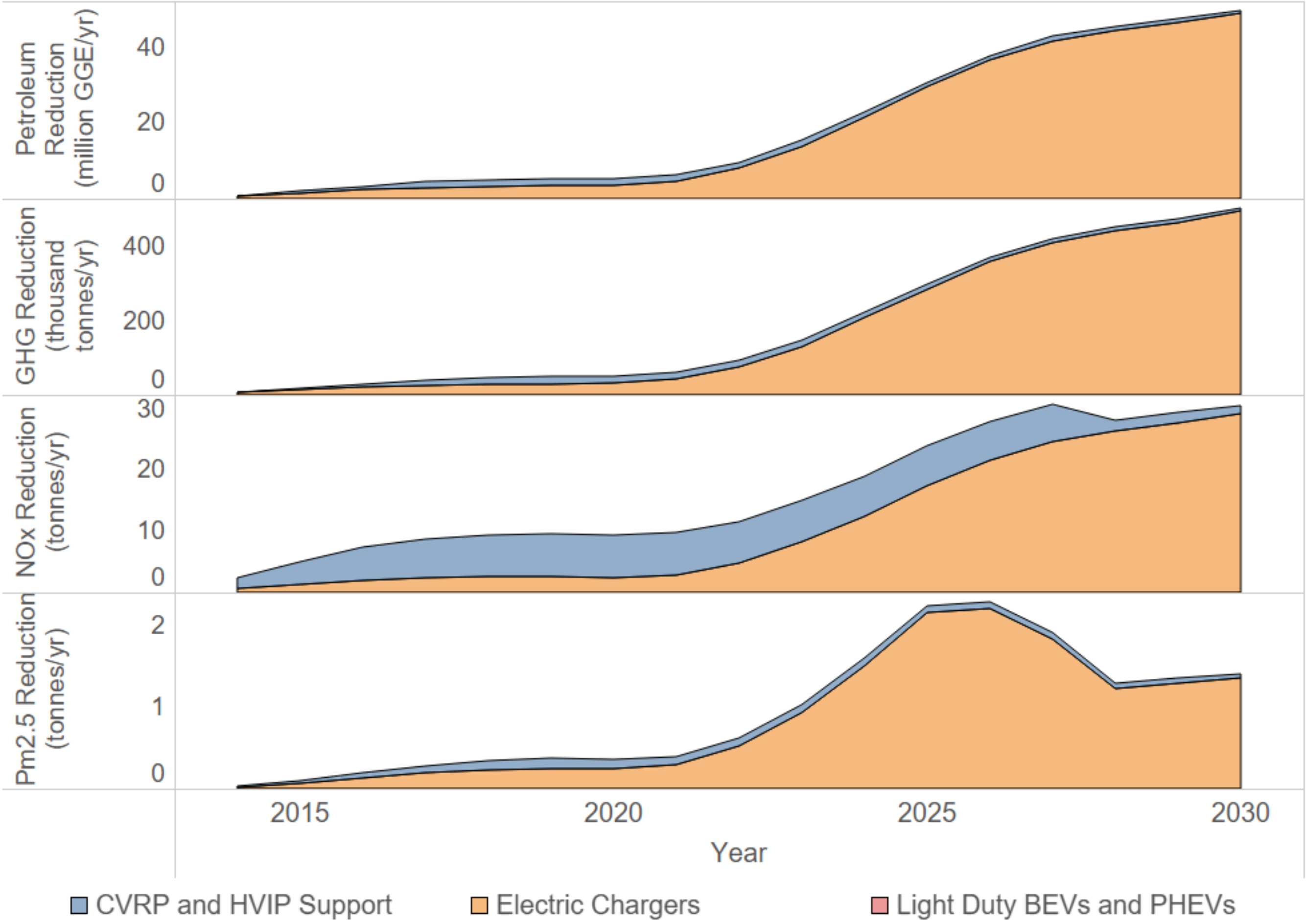
Electric Vehicles Manufacturing

In past analyses, investments aiming to stimulate the manufacturing of electric vehicles yielded large benefits in terms of petroleum and GHG emissions reductions because of the compounding effect each year that vehicles are produced. As of this 2021 analysis, the benefits methodology reflects a change by moving all manufacturing benefits to the market transformation category.

Electric Drive Vehicles and Infrastructure

The CTP's incentives for light-duty BEVs and PHEVs, incentives for electric commercial trucks, and deployment of EVSE have also played a role in reducing the petroleum demand and GHG emissions of the transportation sector in California. In this 2021 analysis, they contributed to a 0.03 million, 1.72 million, and 4.5 million GGE/year petroleum displacement, respectively, which corresponds to 0.25, 16.77, and 42,900 metric tons carbon dioxide (CO_2)/year emissions reduction, as seen in Figure 2. The different lifespans of electric charging stations (25 years) and EVs (16 years) help explain the slow decay of vehicles benefits past 2021, while EVSE benefits are sustained out to 2030. Petroleum and GHG reductions continue to grow somewhat linearly, this is largely due to the influence of CALeVIP. CALeVIP offers incentives for the purchase and installation of EV charging infrastructure at publicly accessible sites throughout California. The CALeVIP project began in 2017 and has a full funding of $200 million. CALeVIP infrastructure investment funds are expected to be fully invested by the project end year of 2025, the rise in electric charger benefits between 2021 and 2025 is due to this expenditure.

Figure 2: Estimated Expected Reductions from EV and EVSE Infrastructure

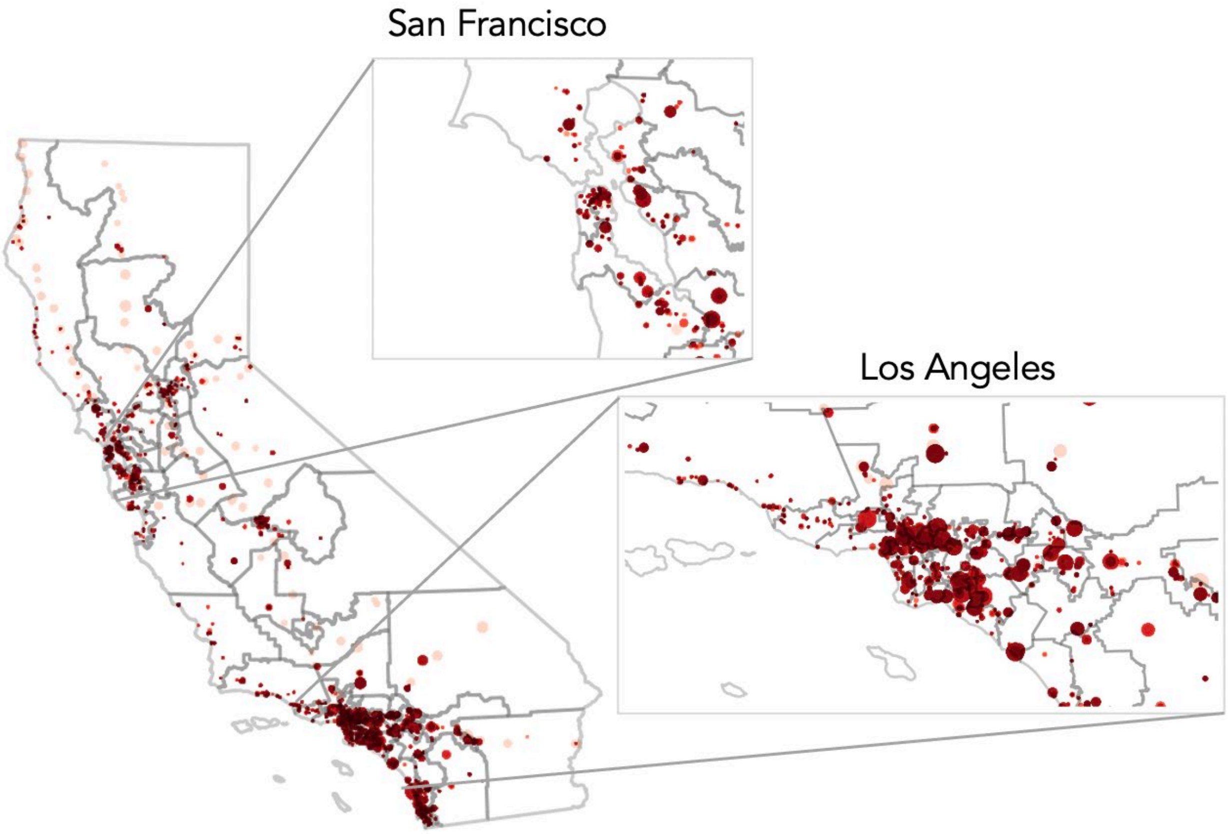


Source: NREL

Mapping EVSE Infrastructure Benefits

Any particular EVSE infrastructure has a static location, so it is reasonable to assume that the benefits occur within a region near the charging station. The exact shape and size of the associated benefits around the EVSE infrastructure depend upon the driving patterns of the vehicles that use the EVSE. However, if the EVSE infrastructure is placed in a dense, urban region, it is likely that the associated benefit density will follow the inverse-square law around the charging station. Thus, a map of the benefits by location of the EVSE infrastructure will provide some insight into the spatial distribution of CTP funded project benefits. Figure 3 shows the cumulative petroleum reduction benefits for CTP by EVSE location through 2030. Seen below, the benefits are spread out across California, with the highest density of benefits in the Los Angeles and San Francisco Bay Areas.

Figure 3: Map of Cumulative Petroleum Reduction Benefits for EVSE Infrastructure



Source: NREL

This figure would look the same for GHG, NOx, and PM2.5 benefits, since the EVSE locations are the same. Table 8 shows total expected pollutant reduction benefits in 2030 alone from EVSE infrastructure.

Table 8: Total Estimated Pollutant Reduction in 2030 from EVSE Infrastructure

Benefit Type	Total Estimated Reduction in 2030
Petroleum Reduction	49.0 million gallons
GHG Reduction	499 thousand tons of CO2 eq
NOx Reduction	2.92 metric tons
PM2.5 Reduction	0.137 metric tons

Source: NREL

Monetized EVSE Infrastructure Benefits

EVSE infrastructure reduces criteria pollutant emissions, including NOx and PM2.5 as calculated above. Reductions in NOx and PM2.5 emissions result in public health benefits. The magnitude of these benefits varies geographically, depending on nearby population and ambient air quality, among other factors. There are some models that attempt to monetize the benefits of reduced air pollution emissions, for example, accounting for reductions in health impacts such as exacerbated bronchitis or asthma and the economic impacts from lost wages due to hospitalization.[20] To approximate the economic value from EVSE that accrue from these types of benefits, the authors used the Estimating Air pollution Social Impact Using Regression (EASUIR) model,[21] developed by Carnegie Mellon University, to complete this analysis. The EASUIR model is available as an online tool in which marginal benefits (2010$/metric ton of emission) are produced for given latitude-longitude coordinates.[22]

The CTP-funded EVSE charging station coordinates were used to determine the monetized benefits associated with the air pollution emission reductions from displacing gasoline fuel. While a given project may build EVSE charging stations in various locations, each station location needs to be considered to estimate monetary benefits. Specific locations were not given for more than 3,900 level 2 residential charge points (approximately 34 percent of all points evaluated). About 20% of the total charge points with charging station coordinates are known to be in disadvantaged communities. As seen in Figure 4, the PM2.5 reduction benefits achieve more than $4 million of cumulative benefits by 2030. Similarly, the NOx reduction achieves more than $3 million in cumulative benefits by 2030. Together, they surpass $10 million in cumulative benefits by 2035.

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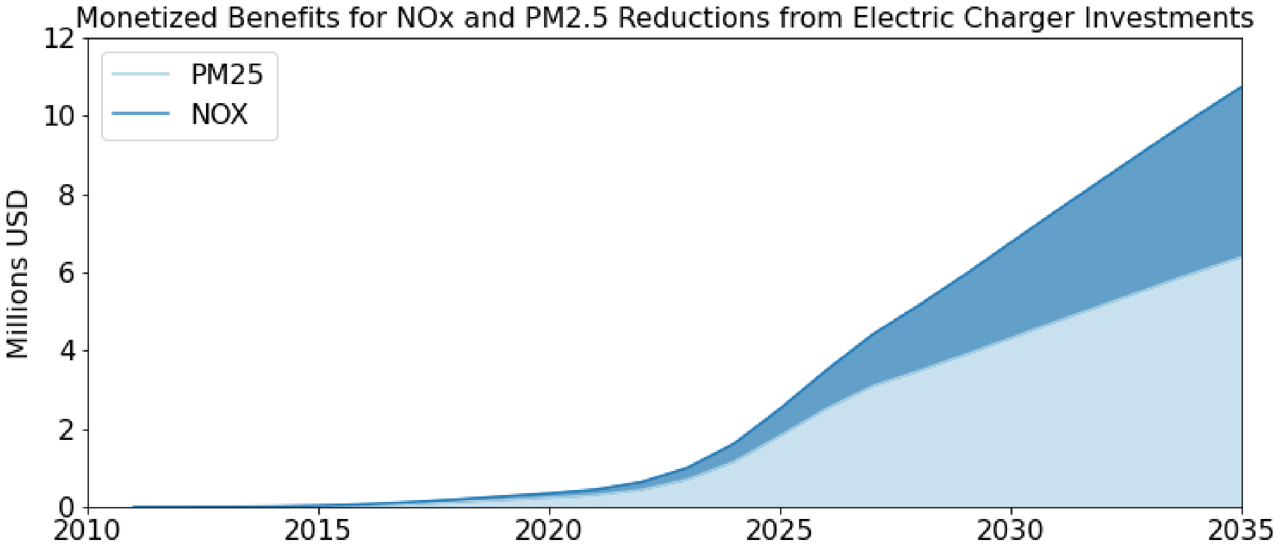
[20] Millstein, D., R. Wiser, M. Bolinger and G. Barbose. 2017. "The Climate and Air-Quality Benefits of Wind and Solar Power in the United States." *Nature Energy,* Vol. 2, No. 17134.

[21] Heo, J., P. J. Adams, and H. O. Gao. 2016. "Public Health Costs of Primary PM2.5 Precursor Emissions in the United States." *Environmental Science Technology,* Vol. 50, pp. 6061-6070.

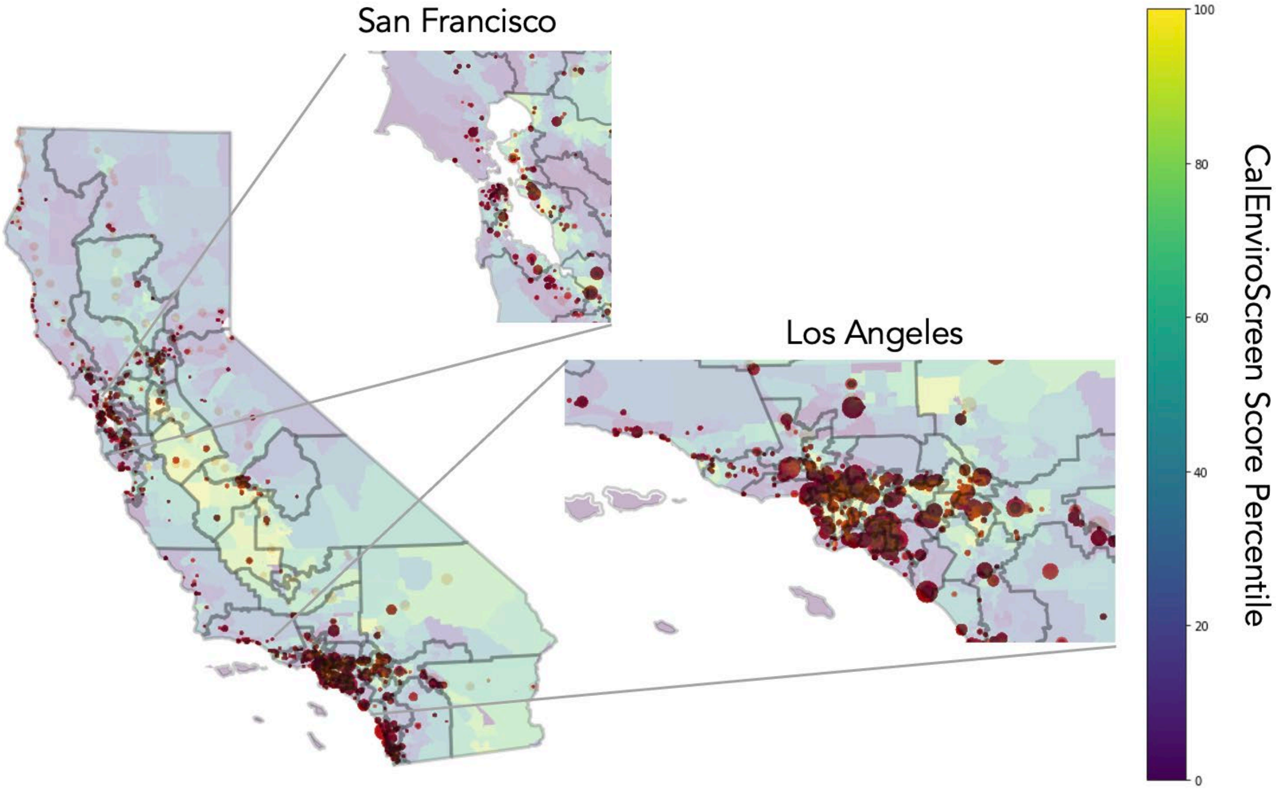
[22] P. J. A. H. O. G. J. Heo. 2016. "Reduced-Form Modeling of Public Health Impacts of Inorganic PM 2.5 and Precursor Emissions." *Atmospheric Environment,* Vol. 137, pp. 80-89.

Figure 4: Cumulative Monetized Benefits from NOx and PM2.5 Reductions from EVSE Investments



Source: NREL

Figure 5: Cumulative Monetized Benefits for NOx and PM2.5 Reductions from EVSE Investments Mapped to Disadvantaged Communities



Source: NREL

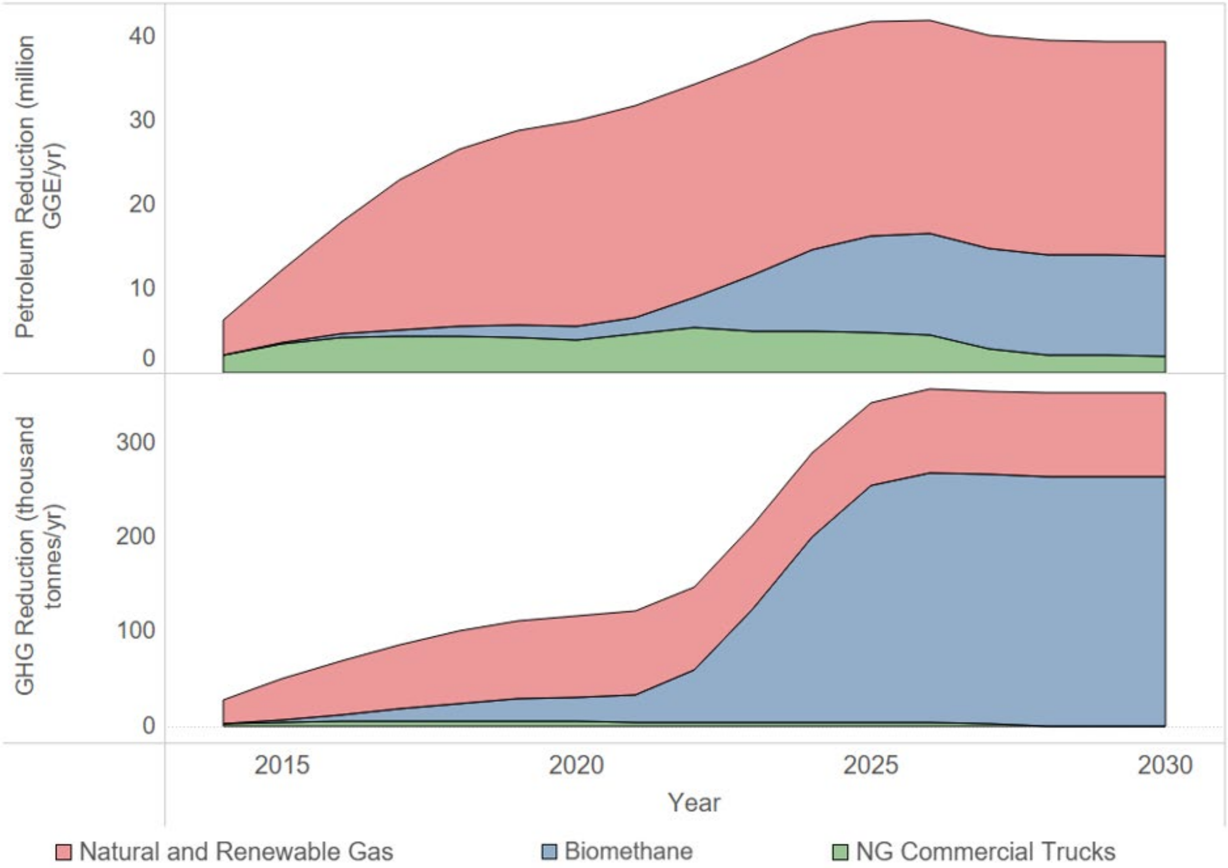
These described monetized air pollution benefits are based on income and population in 2019. Changing the income and population to later years causes monetized benefits to increase. According to the EASUIR model, there is a public health savings of roughly $377,000 in 2030 alone due to PM2.5 emissions reduction and $346,000 due to NOx emissions reduction due to EVSE investments. Figure 5 displays disadvantaged communities with respect to infrastructure investment, disadvantaged communities are any communities greater than 75% according to CalEnviroScreen and appear as yellow on the map.

Gaseous Fuel Vehicles and Infrastructure

Figure 6 shows the expected petroleum reductions from CTP funding for gaseous fuel projects including biomethane, gas commercial trucks, and fossil and renewable gas. Renewable natural gas (RNG) is the product of organic matter breakdown; the distinction in this report between RNG and biomethane is that biomethane is the material produced, while RNG is dispensed via infrastructure. This subset of projects is estimated to reduce petroleum usage by more than 42 million GGE/yr in 2026 and remain relatively constant until the projects end after the 20-year lifespans. The lower panel in Figure 6 also indicates that estimated GHG reductions will reach 356,000 metric tons/yr by 2026 before reducing slightly in 2030.

As seen in the 2014 Benefits Report, the fossil and renewable gas projects are estimated to contribute significantly to the petroleum reductions because of the large fuel throughput. However, the biomethane projects show relatively large GHG emission reductions because of the low GHG emission factors and the associated high equivalent throughputs. Moreover, since the biomethane fuel production and fossil gas delivery projects have long project lifespans (40 and 20 years, respectively), the benefits show very little change through 2030 once all the projects are fully operational.

Figure 6: Estimated Gaseous Fuel Vehicle and Infrastructure Reductions



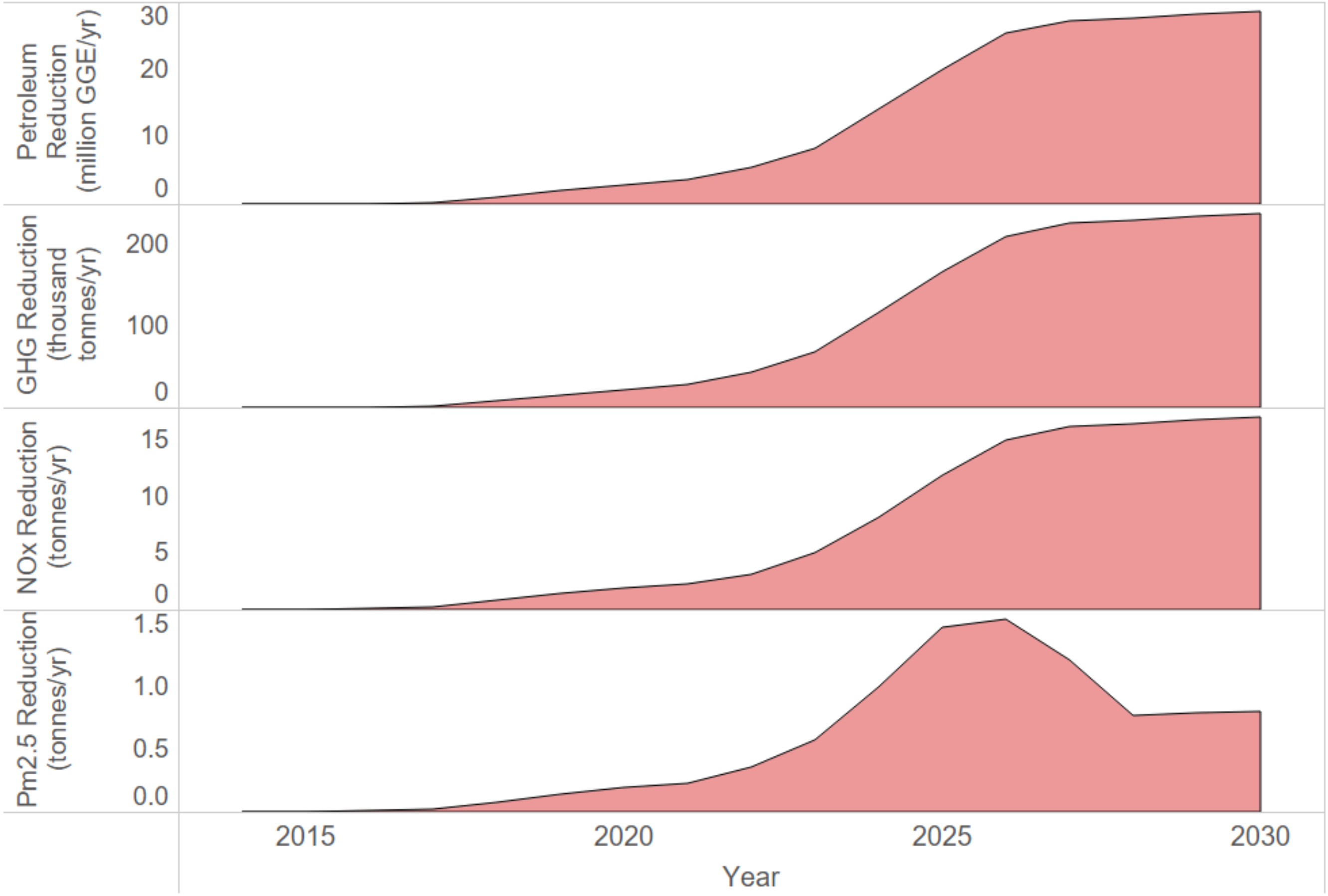
Source: NREL

Hydrogen Infrastructure

Figure 7 summarizes hydrogen refueling station (HRS) infrastructure petroleum reduction benefits. The HRS petroleum reduction benefits begin in 2015 and ramp up at an increasing rate through 2027, in 2030 they plateau near 28.63 million GGE/year reductions. Compared to the 2014 Benefits Report, these estimated petroleum reductions are greater than 9 times as much. These reductions are largely due to the additional investment in hydrogen refueling infrastructure since 2014, as well as the updated calculation method that accounts for the FCEV fuel economy improvements over time, increasing estimated petroleum reductions. Figure 7 also shows the corresponding GHG reductions that follow the same general trend as the petroleum reductions and indicate that by 2030, 235,000 metric tons/year of CO_2e will be reduced.

By 2021, the NOx and PM2.5 reductions reach 2.29 metric tons/year and 0.23 metric tons/year, respectively. The PM2.5 reductions decrease after 2026 due to a steady improvement in conventional vehicle PM2.5 emissions as predicted in the CA-Vision 2.1 model.[11]

Figure 7: Estimated Reductions for HRS Investments



Source: NREL

Mapping Hydrogen Refueling Station Benefits

As with the EVSE infrastructure, the HRS infrastructure is stationary, and vehicles must be in a given area to refuel. Thus, the benefits associated with the vehicles refueling due to the HRS infrastructure are expected to occur near the HRS location. As mentioned earlier, the exact location of the benefits depends on the driving behaviors of the FCEVs, yet it is still insightful to map the benefits simply by HRS location.

Figure 8 shows the HRS petroleum reduction benefits by location of the HRS. As with the EVSE charging infrastructure, the HRS benefits are distributed across California yet are centralized in the urban areas of Los Angeles and the San Francisco Bay Area.

Figure 8: Map of Cumulative Petroleum Reduction Benefits for HRS Infrastructure

Source: NREL

This figure would look the same for GHG, NOx, and PM2.5 benefits, since the EVSE locations are the same. Table 9 shows total expected pollutant reduction benefits in 2030 alone from the Clean Transportation Program funded hydrogen fueling infrastructure projects.

Table 9: Total Estimated Pollutant Reduction in 2030 from Hydrogen Infrastructure

Benefit Type	Total Estimated Reduction in 2030
Petroleum Reduction	28.6 million gallons
GHG Reduction	237.2 thousand tons of CO2 eq
NOx Reduction	1.71 metric tons
PM2.5 Reduction	0.800 metric tons

Source: NREL

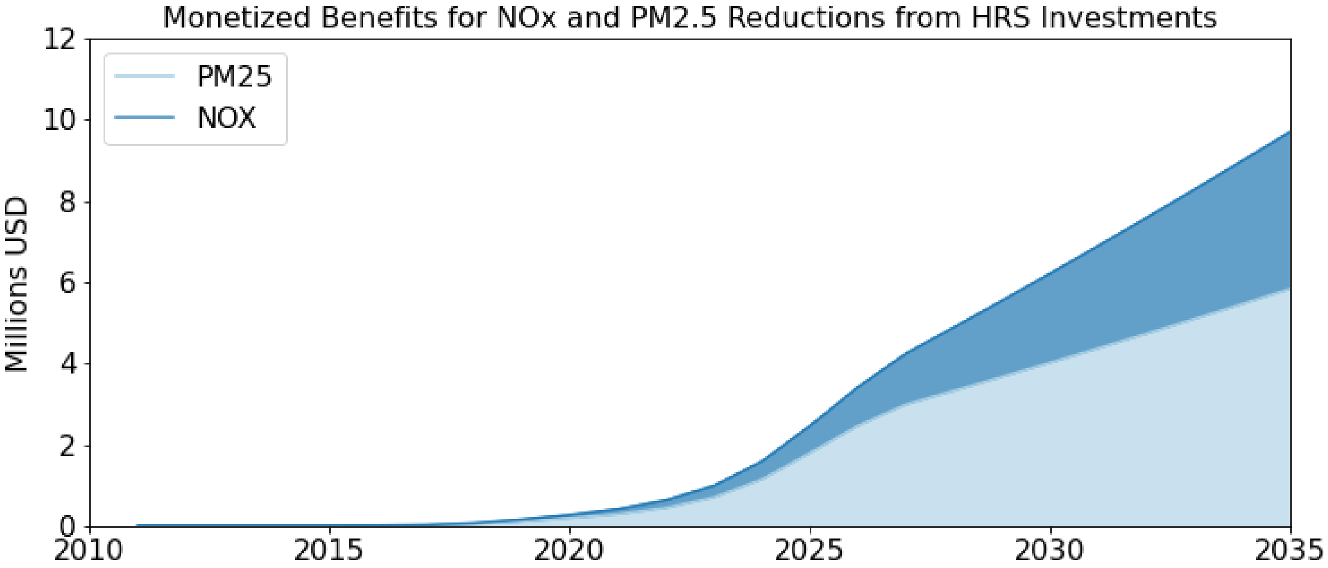
Monetized Hydrogen Refueling Station Benefits

As seen with the EVSE infrastructure, there are public health benefits due to the reduction in NOx and PM2.5 emissions reductions associated with HRSs. The project team used the EASUIR model[21] to determine the monetized air quality improvement benefits by HRS coordinate location.[22]

Based on the locations of the stations, the EASUIR model output benefits ranging from $2,058 to $29,547 per metric ton of NOx and $32,240 to $647,288 per metric ton of PM2.5. Multiplying these marginal benefits by the reductions in NOx and PM2.5 resulted in cumulative benefits to 2030 of about $2.5 million for NOx reductions and $4 million for PM2.5 reductions, in 2010 dollars and 2019 population.

Figure 9 shows the accumulation of cumulative monetized benefits due to NOx and PM2.5 reductions over time.

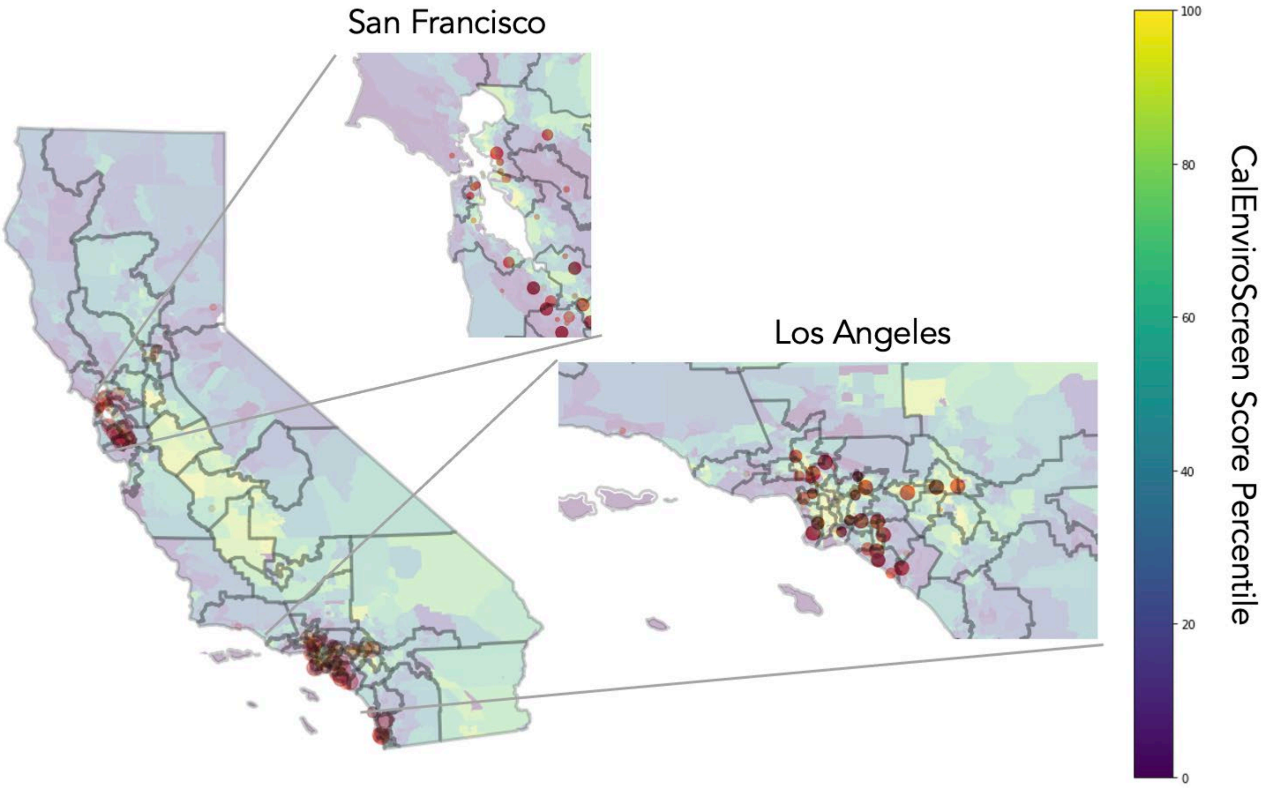
Figure 9: Cumulative Estimated Monetized Benefits for NOx and PM2.5 Reductions from HRS Investments



Source: NREL

About 20% of the total charge points with charging station coordinates are known to be in disadvantaged communities. Figure 10 shows the monetized benefits of NOx and PM2.5 emissions reductions overlaid on a map of disadvantaged communities.

Figure 10: Cumulative Monetized Benefits for NOx and PM2.5 Reductions from HRS Investments Mapped to Disadvantaged Communities



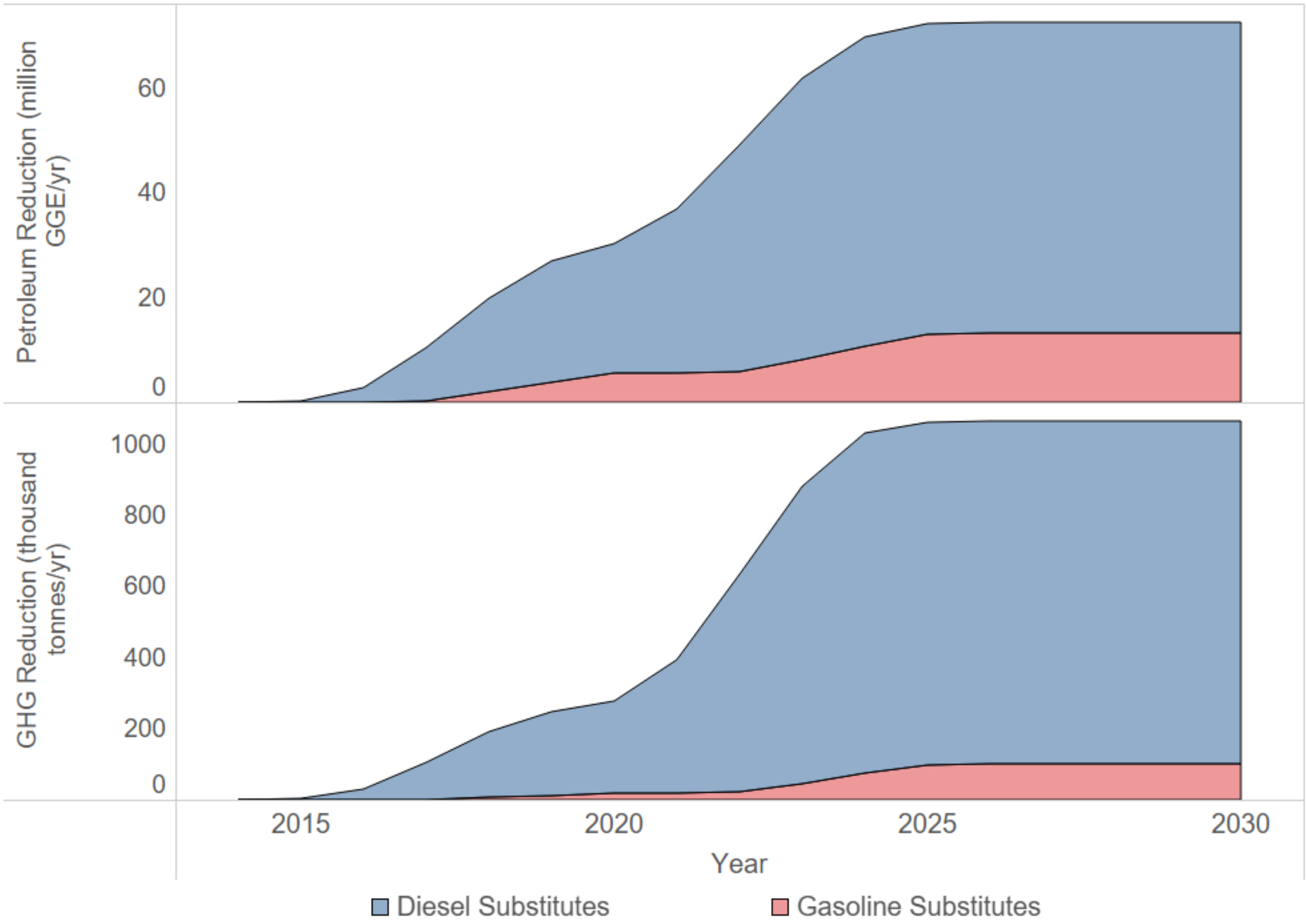
Disadvantaged communities are any communities greater than 75% according to CalEnviroScreen (yellow on map).

Source: NREL

Advanced Fuel Production and Supply Infrastructure

Figure 11 shows the petroleum reductions and GHG emission reductions estimated due to advanced fuel production projects. As seen in both figures, there is a ramp up in benefits starting in 2015, but then flattens out in 2025. This flatline is the result of the larger projects having an expected infrastructure life end date greater than the 2030 window. The estimated petroleum reduction benefits peak at 72.62 million GGE/yr. GHG reductions evolve similarly over time and reach more than 964,000 metric tons/yr in 2025, then plateaus and remains constant through 2030.

Figure 11: Estimated Diesel and Gasoline Substitute-Related Annual Petroleum and GHG Reductions



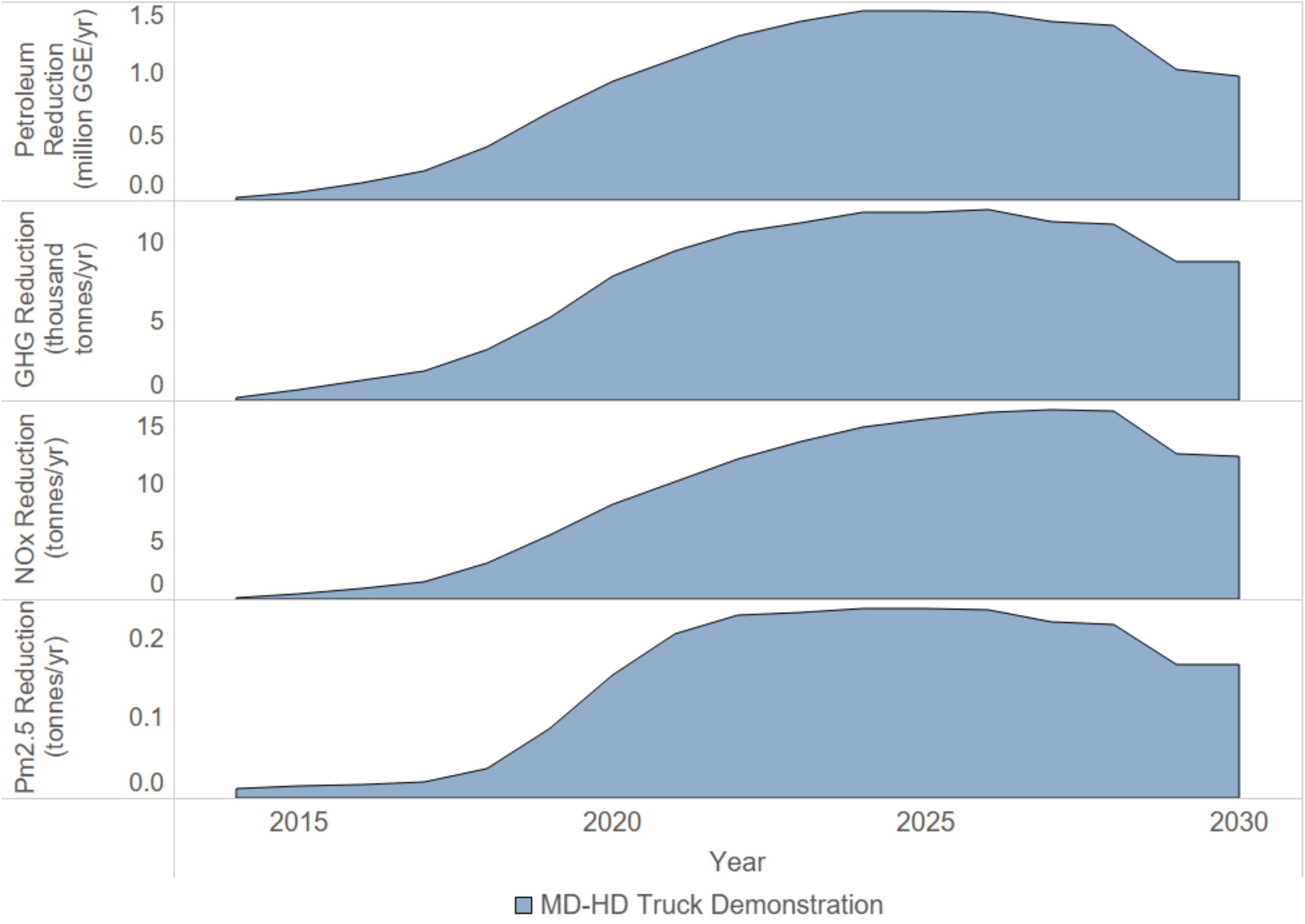
Source: NREL

MD-HD Truck Demonstration Expected Benefits

MD-HD truck demonstration projects encompass CTP-supported projects that aim to build and demonstrate new, advanced vehicle technologies including electric, hydrogen, compressed natural gas, liquefied natural gas (LNG), and diesel fuel types. The annual petroleum reduction benefits for these projects in Figure 12 indicate a gradual increase in benefits up until a peak in 2024 at 1.49 million GGE/DGE displaced. The petroleum reduction benefits then decrease and reach 981 thousand GGE/DGE by 2030. Figure 20 summarizes the GHG reduction benefits, which follow the same trend as the petroleum reduction benefits and reach nearly 8.83 thousand metric tons/yr by 2030.

Figure 12 also shows the NOx and PM2.5 benefits associated with the electric and hydrogen fuel MD-HD truck demonstration projects. The NOx reduction benefits peak in 2028 at 16.5 metric tons/yr. The PM2.5 benefits follow a similar trend as the NOx reduction benefits with a ramp up through 2021 and ending with 0.17 metric tons/year of PM2.5 benefits by 2030.

Figure 12: Estimated Petroleum, GHG, NOx and PM2.5Reductions for MD-HD Truck Demonstration Projects



Source: NREL

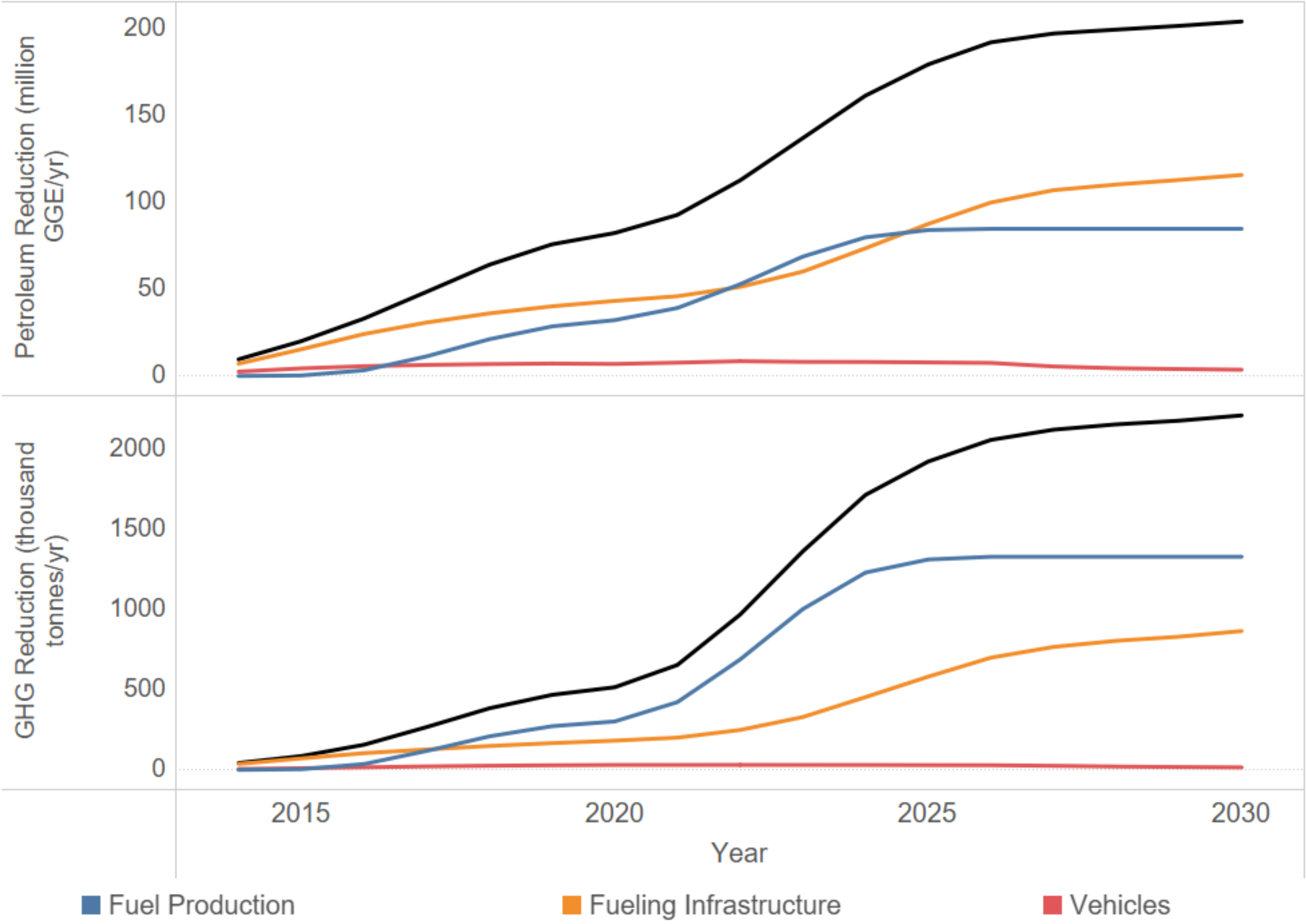
Summary of Expected Benefits

The CTP supports of a wide portfolio of alternative vehicle and fueling infrastructure projects, which has accelerated the development of advanced technologies and led to significant petroleum reduction and air pollution benefits. Expected benefits were calculated for 350 projects, representing $878.1 million of funding. This funding consists of $308.2 million invested in vehicle projects, $430.6 million to fueling infrastructure projects, and $139.3 million to fuel production projects. Figure 13 shows the estimated petroleum reductions for each of these categories through 2030. The total petroleum reduction for all projects is estimated to peak at 203.7 million GGE per year in 2030. Figure 13 also summarizes the estimated total GHG benefits for each of the three major project categories. The estimated GHG benefits for all projects reached nearly 2.2 million metric tons of CO_2e reductions by

2030. The fuel production projects provide the largest portion of the reductions given the associated large fuel throughputs and relatively large GHG emission reduction factors.

Lastly Table 10 and Table 11 show the annual trends in estimated annual petroleum reduction and GHG reduction benefits by project subcategory, respectively. Figure 14 through Figure 19 summarize the relative contributions of each project subcategory on the overall vehicles, fueling infrastructure, and fuel production category estimated petroleum reduction benefits, respectively.

Figure 13: Estimated Petroleum and GHG Reductions by Project Class



Source: NREL

Table 10: Summary of Estimated Expected Annual Petroleum Reduction Benefits (Million Gallons) Through 2030

Project Class	*Project Subclass*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*2021*	*2022*	*2023*	*2024*	*2025*	*2026*	*2027*	*2028*	*2029*	*2030*
Fuel Production	Biomethane	0	0.1	0.4	0.8	1.2	1.5	1.6	2	3.6	6.7	9.8	11.6	12	12	12	12	12
	Diesel Substitutes	0	0.2	2.9	10.2	17.9	23.1	25	31.4	43.1	53.7	59.2	59.4	59.4	59.4	59.4	59.4	59.4
	Gasoline Substitutes	0	0	0	0.3	2	3.9	5.5	5.7	6	8.2	10.7	12.9	13.2	13.2	13.2	13.2	13.2
Fueling Infrastructure	Biodiesel	1.3	3.1	5.2	6.1	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4	6.4
	E85 Ethanol	1	2.1	3.2	3.6	4.3	5.2	5.9	6	6	6	6	6	6	6	6	6	6
	Electric Chargers	0.6	1.4	2.3	2.9	3.2	3.4	3.5	4.5	8	13.8	21.4	29.4	36.5	41.6	44.4	46.6	49
	Hydrogen	0	0	0.1	0.3	1	1.9	2.8	3.6	5.4	8.4	14.1	20.1	25.3	27.3	27.7	28.2	28.6
	Natural and Renewable Gas	4.2	8.7	13.4	17.9	21	23.1	24.5	25.3	25.4	25.4	25.5	25.5	25.5	25.5	25.5	25.5	25.5
Vehicles	CVRP and HVIP Support	0.2	0.5	1	1.5	1.9	2	1.8	1.7	1.6	1.5	1.4	1.4	1.3	1.2	0.9	0.9	0.7
	Light Duty BEVs and PHEVs	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	LPG Commercial Trucks	0.2	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0	0	0	0
	MD-HD Truck Demonstration	0	0.1	0.1	0.2	0.4	0.7	0.9	1.1	1.3	1.4	1.5	1.5	1.5	1.4	1.4	1	1
	NG Commercial Trucks	2	3.5	4.2	4.3	4.3	4.2	3.9	4.6	5.4	4.9	4.9	4.7	4.5	2.8	2.1	2	2

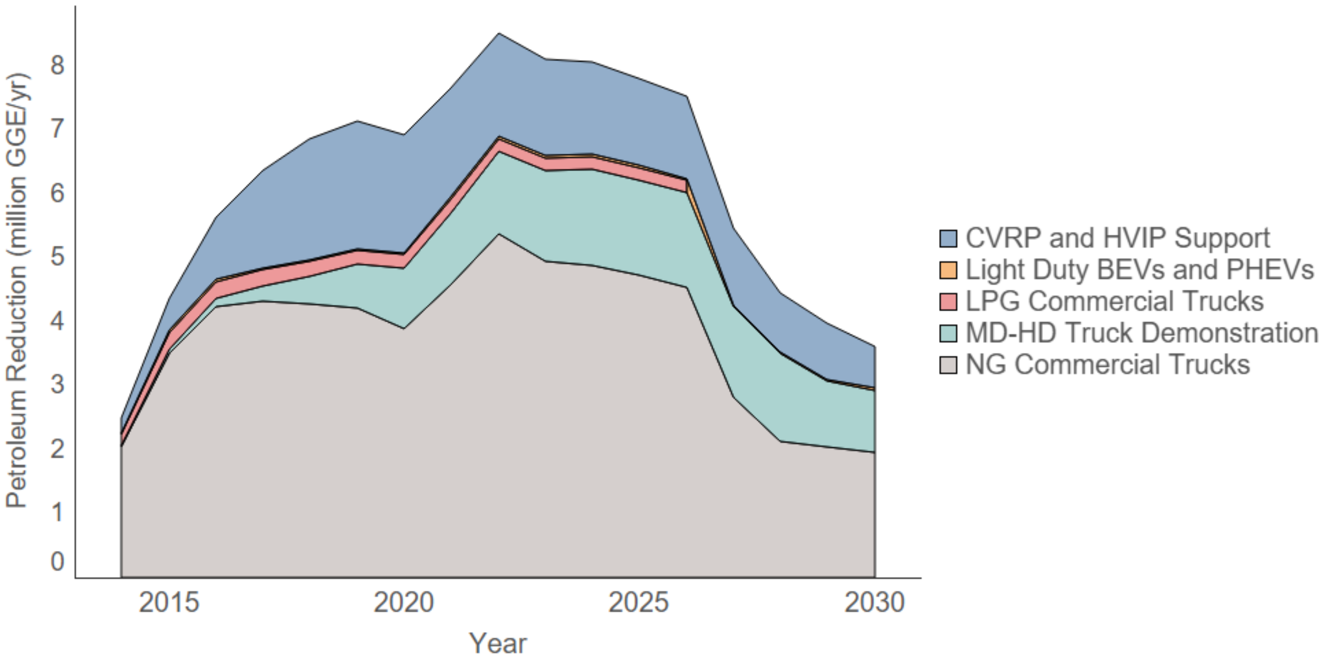
Source: NREL

Table 11: Summary of Estimated Expected Annual GHG Emission Reduction (Thousand Metric Tons CO2) Benefits Through 2030

Project Class	*Project Subclass*	*2014*	*2015*	*2016*	*2017*	*2018*	*2019*	*2020*	*2021*	*2022*	*2023*	*2024*	*2025*	*2026*	*2027*	*2028*	*2029*	*2030*
Fuel Production	Biomethane	0.2	2.2	6.1	12.8	19.3	23.9	25.5	29.0	55.2	121.1	197.4	250.8	264.4	264.4	264.4	264.4	264.4
	Diesel Substitutes	0.0	1.9	30.3	104.5	183.4	236.1	258.8	375.4	612.0	836.4	960.3	964.0	964.0	964.0	964.0	964.0	964.0
	Gasoline Substitutes	0.0	0.0	0.0	1.0	6.6	12.9	18.2	18.8	22.4	46.9	75.0	99.4	102.8	102.8	102.8	102.8	102.8
Fueling Infrastructure	Biodiesel	3.5	8.4	15.5	20.5	23.5	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0	24.0
	E85 Ethanol	2.9	6.3	9.6	10.8	13.1	15.6	17.8	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1	18.1
	Electric Chargers	5.4	12.9	20.9	25.5	28.6	30.4	33.3	42.9	76.0	131.4	207.5	285.2	360.6	411.4	445.4	467.4	499.0
	Hydrogen	0.0	0.0	0.8	2.4	8.0	14.8	21.5	28.1	42.6	67.7	116.0	166.1	209.4	225.7	229.8	233.5	237.2
	Natural and Renewable Gas	25.4	43.9	57.7	68.2	76.2	82.3	86.2	88.2	88.6	88.7	88.8	88.9	88.9	88.9	88.9	88.9	88.9
Vehicles	CVRP and HVIP Support	2.4	5.1	9.4	14.4	17.5	18.5	18.1	16.8	15.9	15.0	14.4	13.6	13.2	12.4	9.4	9.0	6.7
	Light Duty BEVs and PHEVs	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.4	0.4	0.5	0.5	0.3	0.3	0.2	0.2	0.2
	LPG Commercial Trucks	0.5	0.6	0.7	0.6	0.6	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5	0.0	0.0	0.0	0.0
	MD-HD Truck Demonstration	0.2	0.7	1.3	1.9	3.2	5.3	7.9	9.5	10.7	11.3	12.0	12.0	12.1	11.4	11.2	8.9	8.8
	NG Commercial Trucks	2.2	3.8	4.7	4.6	4.4	4.2	4.0	3.8	3.6	3.4	3.3	3.2	3.0	1.5	-0.1	-0.1	-0.1

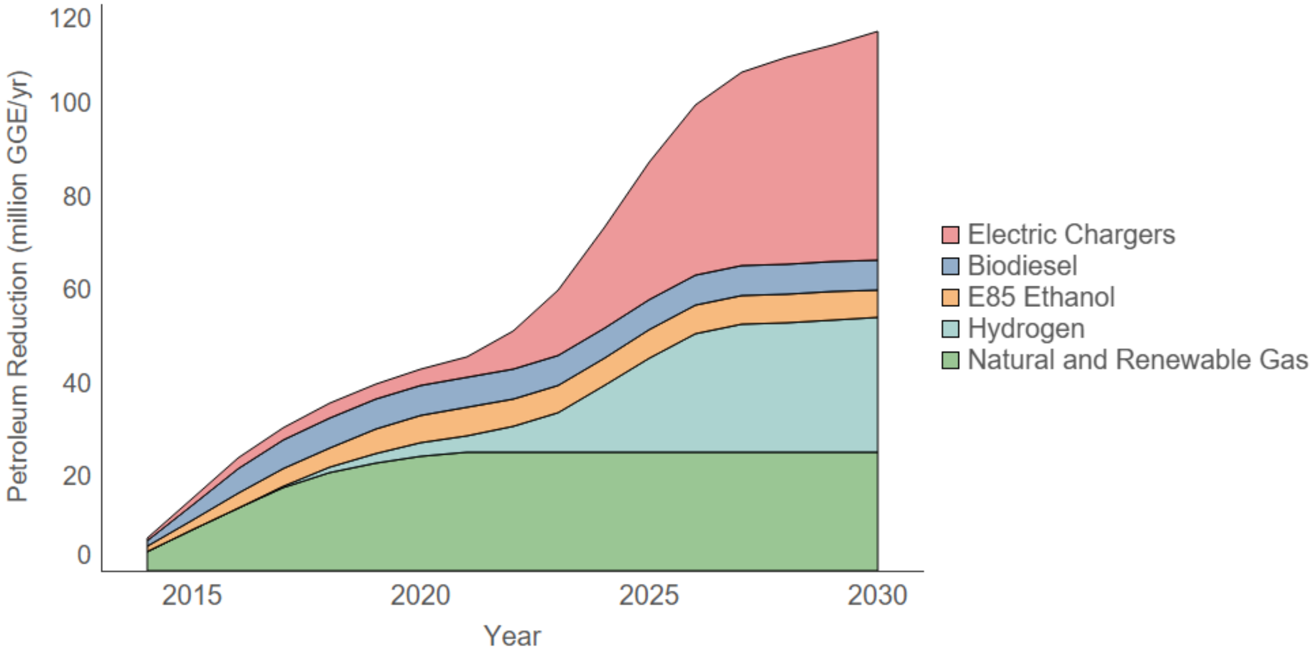
Source: NREL

Figure 14: Summary of Estimated Petroleum Reduction Benefits from Vehicles Projects by Subcategory



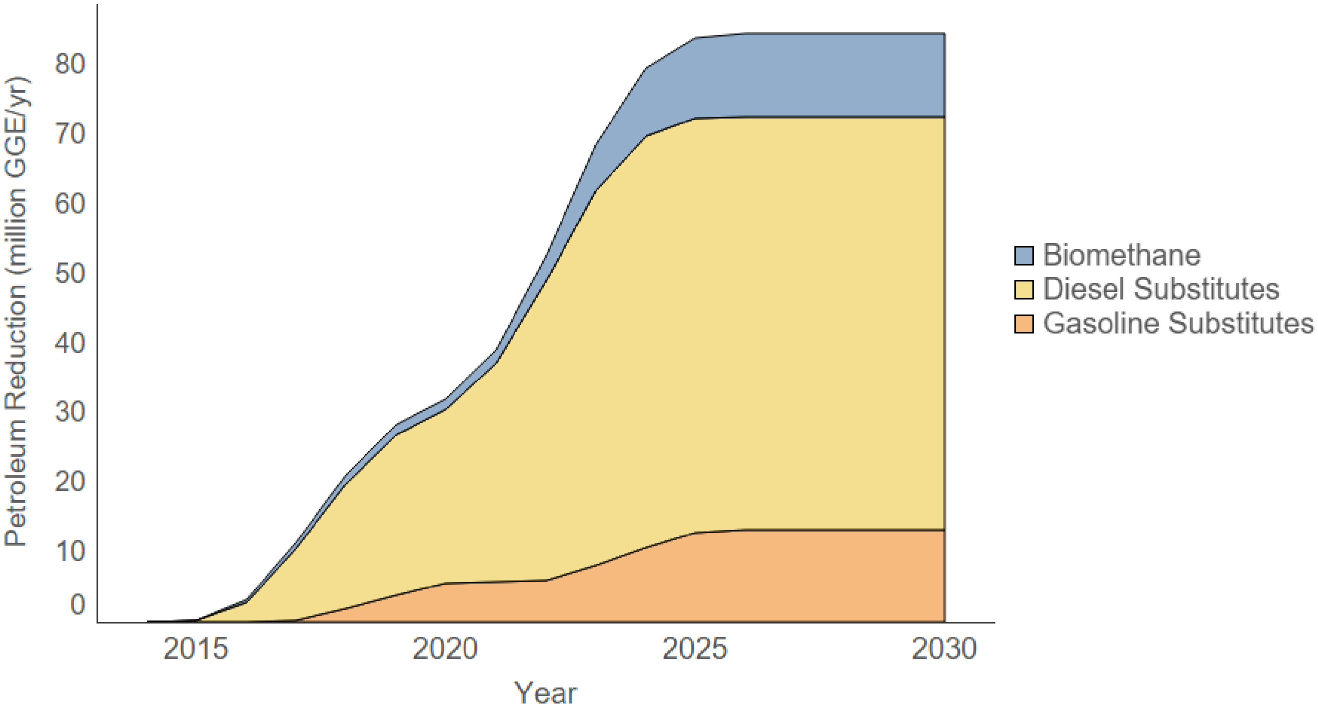
Source: NREL

Figure 15: Summary of Estimated Petroleum Reduction Benefits from Fueling Infrastructure Projects by Subcategory



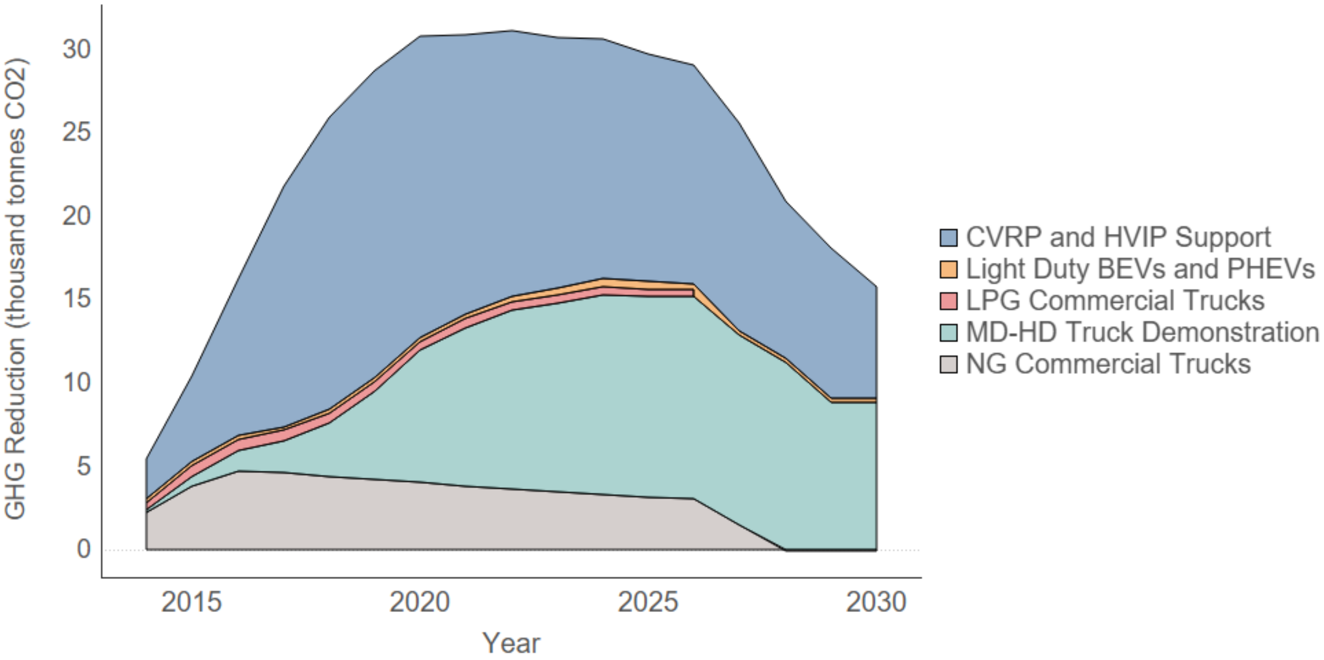
Source: NREL

Figure 16: Summary of Estimated Petroleum Reduction Benefits from Fuel Production Projects by Subcategory



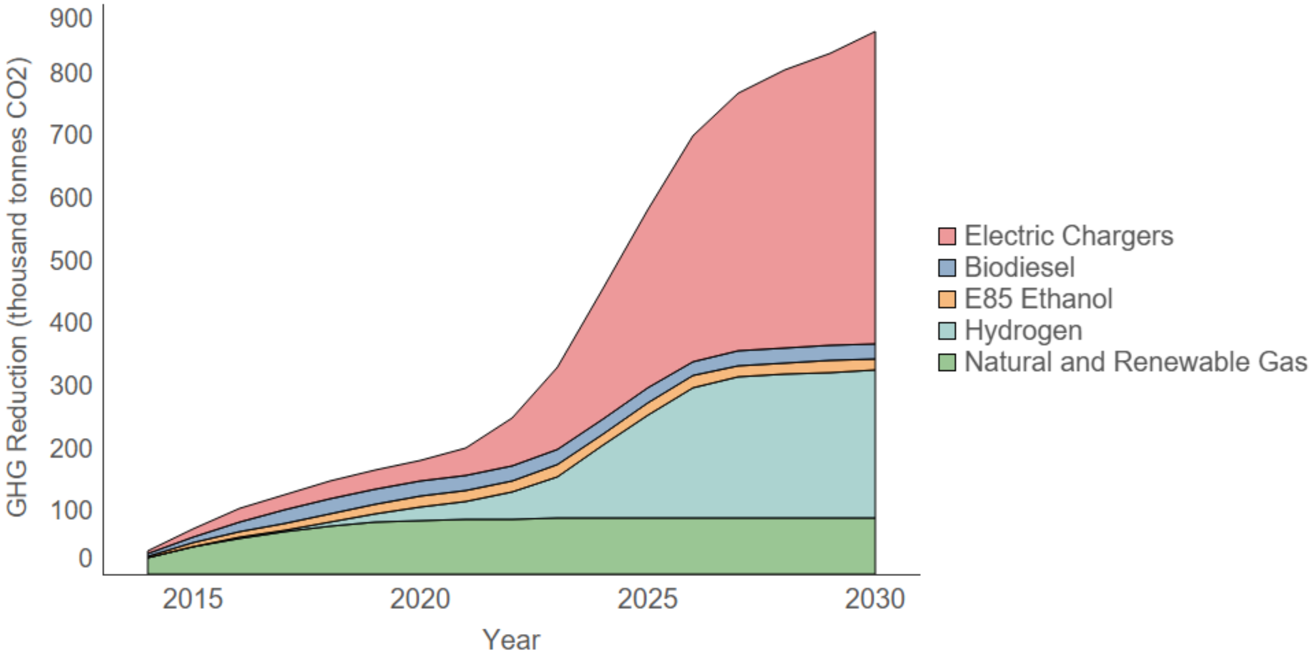
Source: NREL

Figure 17: Summary of Estimated GHG Reduction Benefits from Vehicles Projects by Subcategory



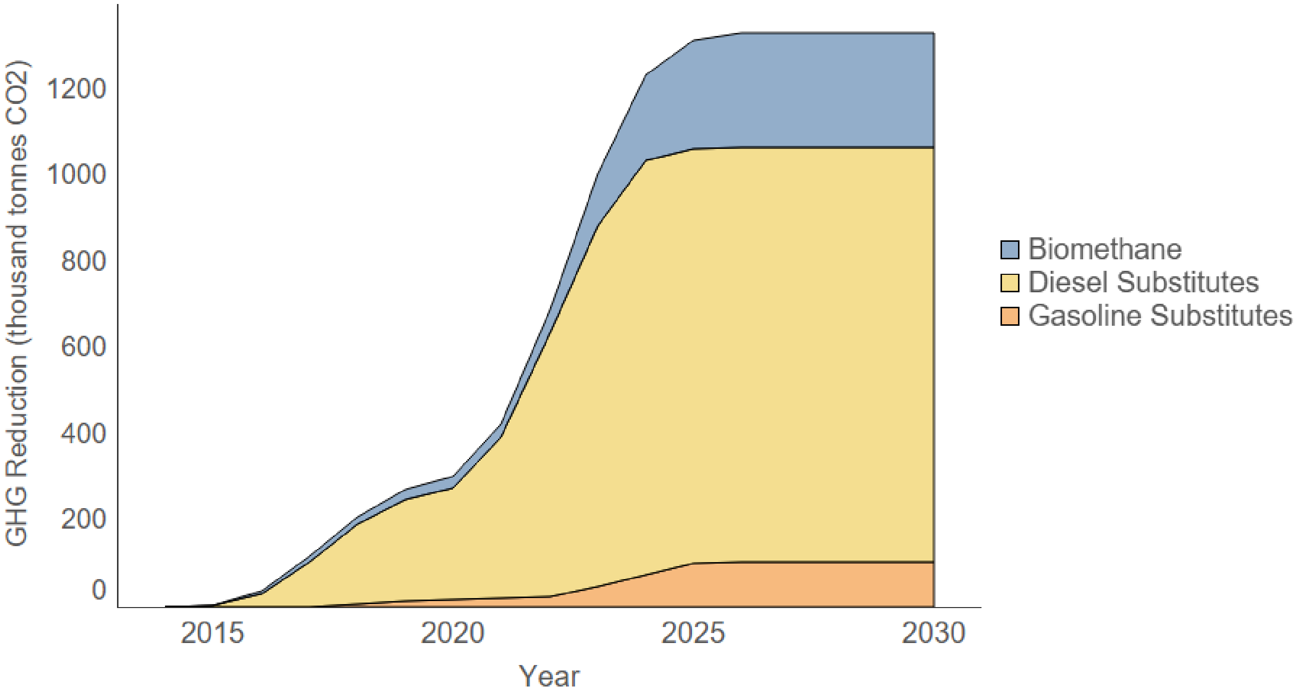
Source: NREL

Figure 18: Summary of Estimated GHG Reduction Benefits from Fueling Infrastructure Projects by Subcategory



Source: NREL

Figure 19: Summary of Estimated GHG Reduction Benefits from Fuel Production Projects by Subcategory



Source: NREL

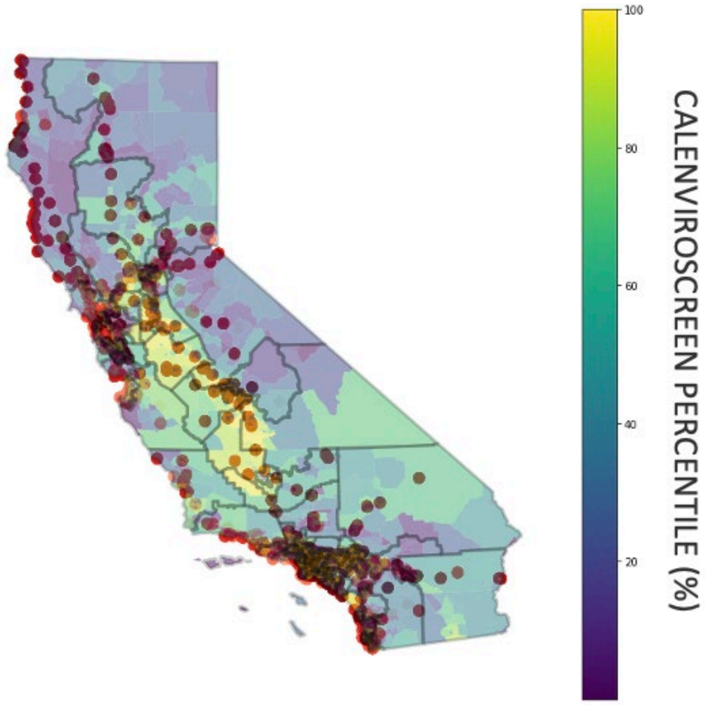
Estimating Equity and Social Benefits

To estimate equity and social benefits, a spatial disaggregation was performed such that the benefits were regionalized throughout California. While this analysis could only be performed for fueling infrastructure and vehicle projects, since they had geospatial attributes or could be accounted for spatially using existing NREL data, a large majority (roughly 85%) of total funding contributes to fueling infrastructure or vehicle projects.

For fueling infrastructure projects, including the light-duty EV charging stations and hydrogen refueling stations, it is assumed that most benefits occur in the vicinity of those stations. To disaggregate the benefits of vehicles projects, NREL internal HD truck travel data was used. Here, it was assumed that a greater penetration of truck instances in a census tract correlated to a greater proportion of benefits if those trucks were electrified.

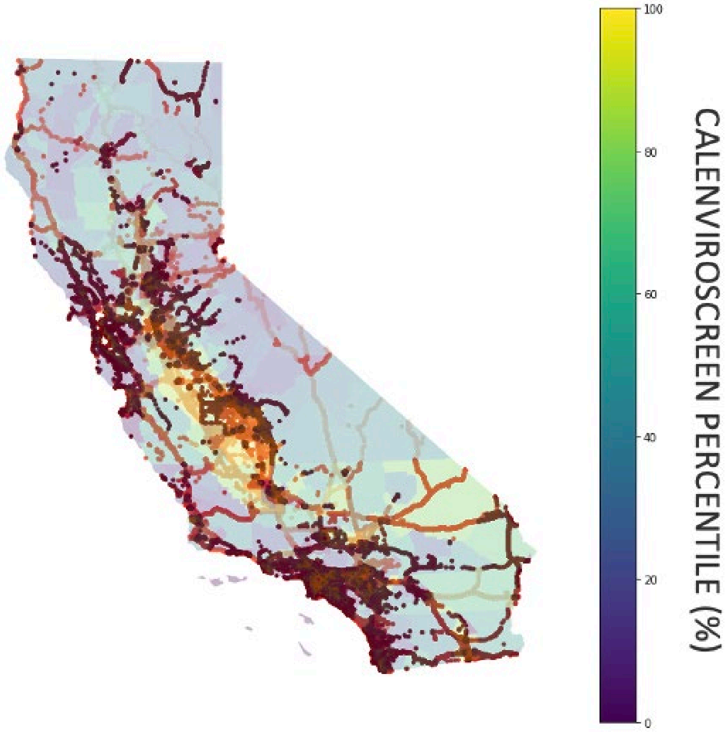
Figure 20 shows the location of the EVSE and HRS stations using geospatial information provided by CEC, and Figure 21 shows truck instances throughout California. While truck travel appears common in San Francisco and Los Angeles metropolitan areas, a large concentration of travel also occurs in midland California where the CalEnviroScreen 3.0 percentile is greater (denoting more many disadvantaged communities).

Figure 20: Map of EVCS and HRS station locations



Source: NREL

Figure 21: Location of HD truck instances



Source: NREL

Once benefits were mapped to specific latitude/longitude coordinates, they were aggregated up to the census tract level. This allowed for mapping to disadvantaged communities using CalEnviroScreen 3.0 or to low-income communities using data provided by the CEC.

Spatially disaggregating benefits by census tract, we estimate that roughly 40% of reductions happen in disadvantaged communities (Table 12) and roughly 70% of reductions occur in low-income communities (Table 13).

Table 12: Summary of Expected Benefits to Disadvantaged Communities in 2030

Metric	Disadvantaged Community Benefits	Total Benefits	Percentage of Benefits to Disadvantaged Communities
Petroleum Reduction (millions of gallons)	52.81	139.01	38%
GHG Reduction (thousand metric tons CO2eq)	580.01	1452.85	40%
NOx Reduction (metric tons)	376.7	717.12	53%
PM2.5 Reduction (metric tons)	14.9	28.55	52%

Source: NREL.

Table 13: Summary of Expected Benefits to Low Income Communities in 2030

Metric	Low Income Community Benefits	Total Benefits	Percentage of Benefits to Low Income Communities
Petroleum Reduction (millions of gallons)	90.24	139	65%
GHG Reduction (thousand metric tons CO2eq)	958.14	1452.75	66%
NOx Reduction (metric tons)	521.1	717.03	73%
PM2.5 Reduction (metric tons)	20.7	28.55	73%

Source: NREL.

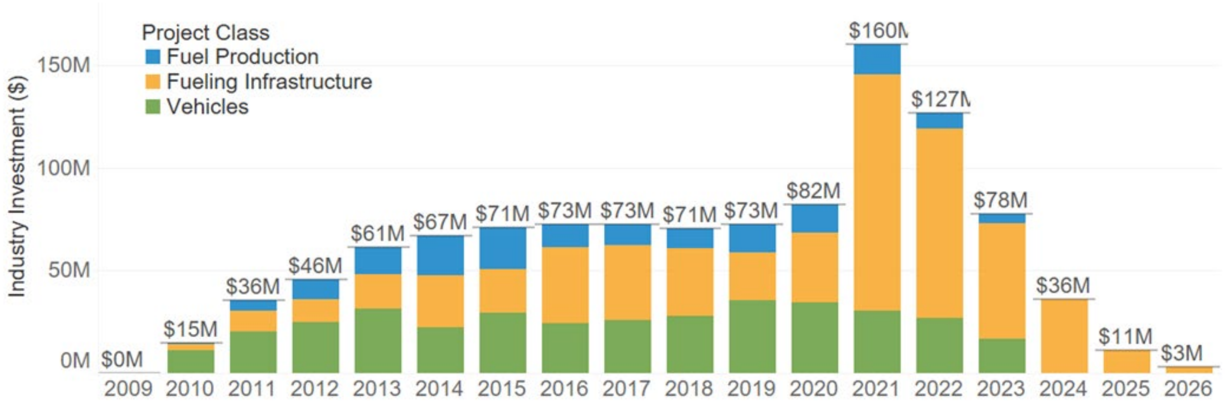
Estimating Job Creation Benefits

Economic Impact Analysis for Planning (IMPLAN) is a platform for estimating the total impact 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 (SAMs) that include sectoral, demographic, and governmental data reflecting how the economy of the region operates in a certain year. It reflects economic flows between sectors, consumers, and institutions at the state, county, and zip-code levels.

These analyses are performed using an input-output (IO) model, one of the most common and straightforward methods for estimating economy-wide impacts induced by a change in demand of a given sector (that is, an increased demand for construction). The demand-driven IO model is composed of several equations reflecting each sector's production function and represent the structure of an economy as a network of sectors that sell to one another, to local households and governments, 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 or services in a region. Using California-specific multipliers (derived from IMPLAN), we estimated the direct, indirect, and induced effects in employment, taxes, and gross domestic product from the CTP investments over the 2010-2021 period and the expected investment up to 2025.

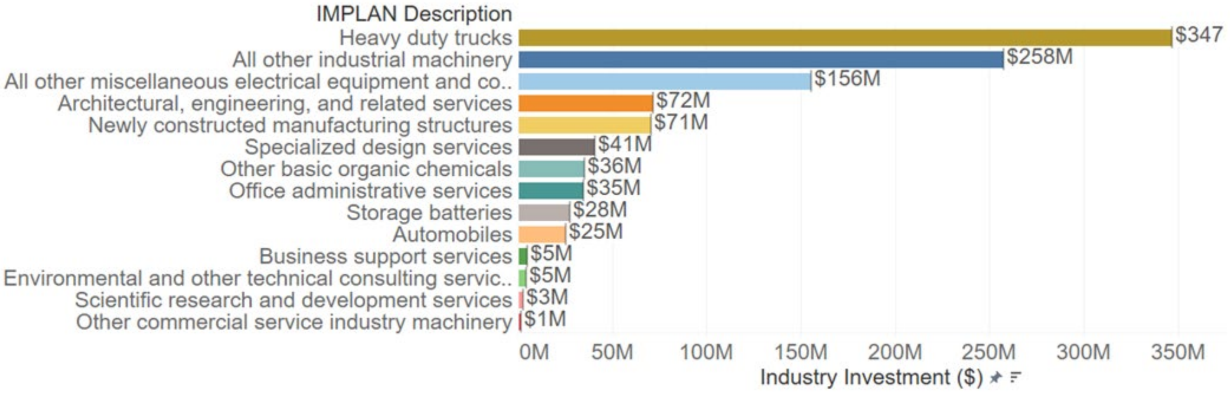
A total of $1.001 billion of project investment was accounted for between 2010-2025, where a typical CEC CTP yearly investment was $60-80M/year (Figure 22). IMPLAN's dataset are highly disaggregated (500+ sectors), and thus the first step of the analysis requires allocating the annual CTP investment among those industries. Each project investment was broken down using project proposal budgets and mapped to different NAICS codes that reflect the sector which supplied the required goods or services[23] (Figure 23). Because most of the investments are focused on zero-emission vehicles and required infrastructure (particularly electrical vehicles and chargers), a large portion of the impacts were allocated to the "Heavy Duty Trucks Manufacturing" and "Electrical Equipment Manufacturing" sectors.

Figure 22: Total investment (CEC) per year



Source: CEC

Figure 23: Distribution of investments among sectors



Source: CEC

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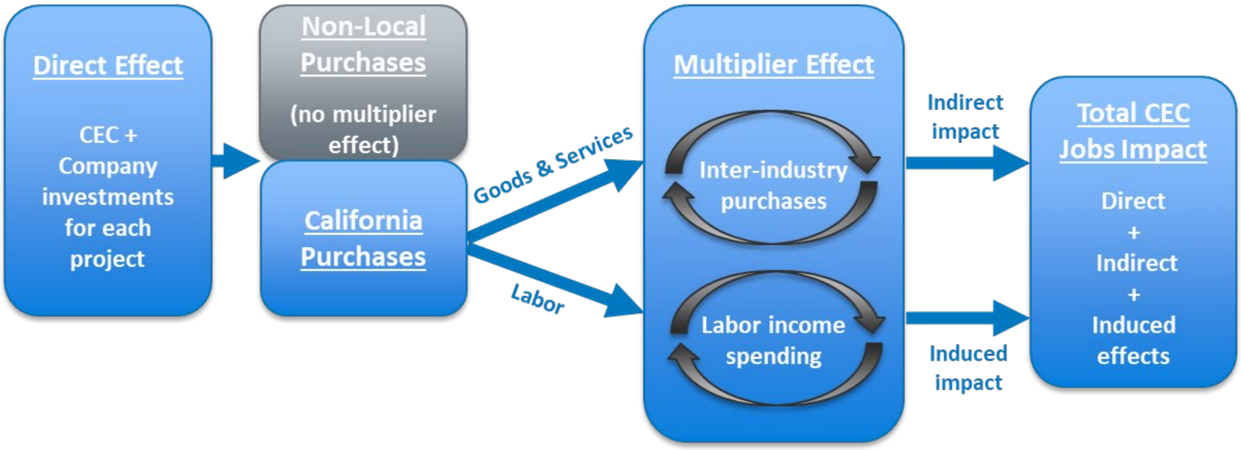
[23] For this analysis we have used the existing sectors in IMPLAN, which reflect an average production scheme of and industry for the entire state. IMPLAN currently does not provide enough sectoral disaggregation to reflect sectors such as battery electric or fuel cell vehicles manufacturing, only a sector that blend those with internal combustion vehicles.

From the total investments in a year (direct effect), part of the goods and services are provided by companies outside California (non-local purchases) and do not generate local impacts (Figure 24). Those are excluded from the analysis using IMPLAN's regional purchase coefficients (RPCs) that determine the percentage of local purchases for each good/service in the model (RPCs vary by year, due to the evolving regional economic structure). 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. Impacts can be classified as direct, indirect (from supply-chain linkages) and induced (resulting from the spending of wages/salaries by workers) by year. For this analysis, we have used contemporaneous models from 2010-2019 (most recent year available). Impacts from 2020-2025 were estimated using the 2019 SAM. Occupational information, including types of occupations, average wages, as well as education, experience and training requirements are based on IMPLAN's Occupational Dataset for 2019.

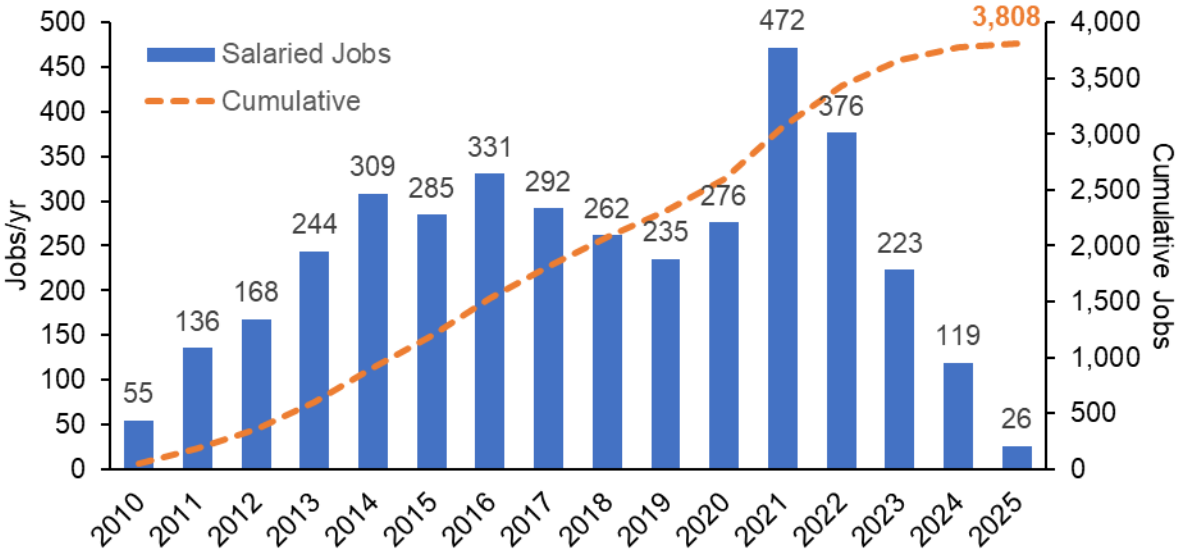
Figure 24: Job analysis IMPLAN's workflow



Source: NREL

A total of nearly 4,000 full-time jobs have been and are expected to be supported in California due to CEC investments between 2010-2025, with a typical yearly job creation of roughly 200-400 jobs. However, over half of the direct impact of some high investment sectors is estimated to occur outside of California (that is , goods and services supplied by domestic/foreign imports). High levels of automation in manufacturing results in relatively low job creation statistics (that is, roughly 3 jobs created per $1M invested in vehicle manufacturing).

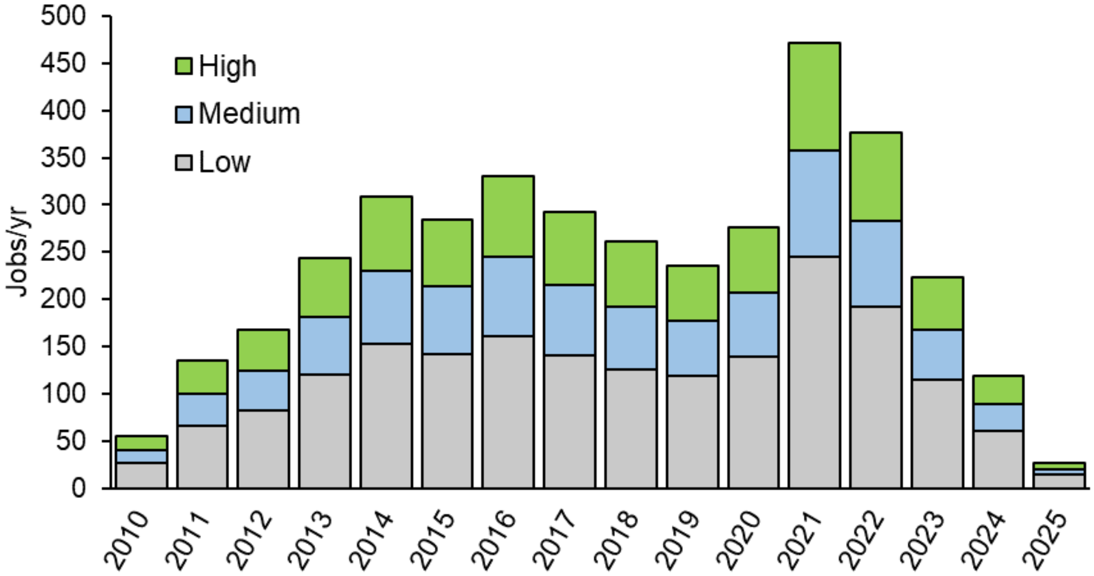
Figure 25: Total salaried jobs created by year



Source: NREL

The average profile of the jobs created are shown for 2021, the year with the most investments. As shown in Figure 26 , most jobs are low skilled (that is, require a high school diploma or less) and these account for 50% of all jobs created over the period. Almost a quarter of jobs required no previous experience (Figure 26) and average salaries were clustered in the $40-$70k/yr range, with median wage distribution higher than those from California in 2019 (Figure 28). One third of the jobs created were in the sales and administrative support occupations and 9% in manufacturing jobs (Table 14).

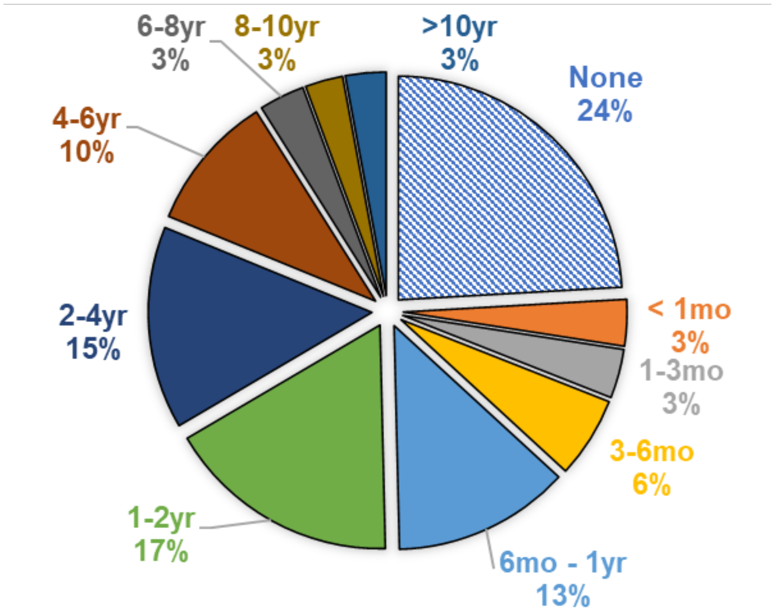
Figure 26: Total employment by skill level per year



Source: NREL

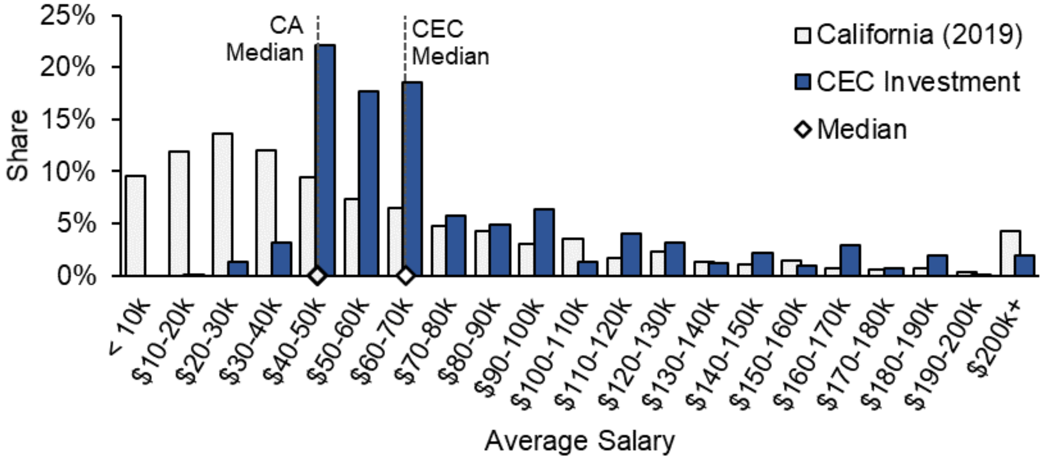
Note: Low skill: high school diploma or less; Medium skill: associate degree or less; High skill: bachelor's degree or more.

Figure 27: Distribution of required experience for jobs created in 2021



Source: NREL

Figure 28: Average wage distribution for jobs created in 2021 (2019 dollars)



Source: California data based on Census' American Community Survey from https://datausa.io/

Table 14: Share of employment by occupation, jobs created in 2021

Code	Occupation Group	Share
11-0000	Management Occupations	6%
13-0000	Business and Financial Operations Occupations	6%
15-0000	Computer and Mathematical Occupations	3%
17-0000	Architecture and Engineering Occupations	4%
19-0000	Life, Physical, and Social Science Occupations	1%
21-0000	Community and Social Service Occupations	1%
23-0000	Legal Occupations	0%
25-0000	Educational Instruction and Library Occupations	1%
27-0000	Arts, Design, Entertainment, Sports, and Media Occupations	3%
29-0000	Healthcare Practitioners and Technical Occupations	3%
31-0000	Healthcare Support Occupations	2%
33-0000	Protective Service Occupations	1%
35-0000	Food Preparation and Serving Related Occupations	6%
37-0000	Building and Grounds Cleaning and Maintenance Occupations	2%
39-0000	Personal Care and Service Occupations	2%
41-0000	Sales and Related Occupations	16%
43-0000	Office and Administrative Support Occupations	16%
45-0000	Farming, Fishing, and Forestry Occupations	0%
47-0000	Construction and Extraction Occupations	7%
49-0000	Installation, Maintenance, and Repair Occupations	5%
51-0000	Production Occupations	9%
53-0000	Transportation and Material Moving Occupations	7%
99-0000	Military	0%

Source: NREL

CHAPTER 3: Market Transformation Benefits

As in the 2014 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 CTP funding, influencing fundamental market forces to accelerate the adoption of advanced vehicle and fuel technologies. Shifting market forces or reducing market barriers occurs through mechanisms that are distinct from the expected benefits calculated in Chapter 2, and the two categories are therefore considered additive. For example, completion of a novel, small-scale biogas production plant would result in displacement of the diesel fuel that would have been used in the trucks that now use biogas (expected benefit), while the proven track record of the novel production technology increases the likelihood of attracting additional private capital and contributes to the success of future technology innovations (market transformation benefit). Consistent with the 2014 Benefits Report, three main market transformation influences are evaluated, each occurring through one or more CTP project types:

1. Vehicle price reductions

   a. Reduction in the price of PEVs due to CVRP rebates.
   b. Reduction in the perceived price of PEVs due to increased availability of public EVSE stations in the form of Willingness to Pay (WTP).
   c. Reduction 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.

3. Next-generation technologies

   a. Additional biofuel production facilities or advanced trucks deployed as a result of CTP support for the current generation of the same technology.

This update report relies upon the same market transformation calculation framework used in the 2014 Benefits Report as well as the 2017 benefits analysis. Although the alternative fuel and advanced vehicle industries have developed since 2014, both are in similarly early stages of innovation and market commercialization and are therefore best represented by the same fundamental analytic framework conducted previously. Where new project or market data have become available, input values and parameters have been updated accordingly. Refer to Section 3.1 in the 2014 Benefits Report to for a detailed explanation of the calculation method.

Vehicle Price Reductions

Price reductions of advanced vehicles relative to conventional or competing vehicles (for example, hybrid electric gasoline vehicles) will tend to increase sales. Projects funded by the CTP tend to increase sales through two mechanisms: actual price reductions resulting from CVRP and perceived price reductions due to increased availability of recharging infrastructure and hydrogen refueling infrastructure. The analytic framework relied upon to represent these market influences are reviewed in Section 3.1.1 of the 2014 Benefits Report. Here the authors provide an overview of the main equations[24] used to estimate increased market share as a result of a vehicle price change.[25]

Additional sales in numbers of vehicles sold per year (DQ) due to reduced price are calculated as the change in market share (S) times the total base sales of the incumbent and advanced vehicles. This equation is shown in Figure 29.

Figure 29: Increased Market Share Equation

$$(\mathrm{S}_{\mathrm{P2*}}\text{-}\mathrm{S}_{\mathrm{P2}}) \cdot (\mathrm{Q}_1 + \mathrm{Q}_2)$$

$$\Delta Q_2 = (S_{P2*} - S_{P2}) \cdot (Q_1 - Q_2)$$

Source: NREL

Where S_{P2} is the initial sales share of the advanced vehicle, S_{P2*} is the increased sales share of the advanced vehicle resulting from the CTP project, Q_1 is the annual sales of the conventional vehicle within the market segment, and Q_2 is the initial annual sales of the advanced vehicle.

The sales share is determined as a function of the conventional vehicle price (P1) and the price of the advanced vehicle (P2) using the logit function shown in Figure 30.

Figure 30: Sales Share Function

$$S_{P2} = \frac{exp[\mu(P_2 - P_1)]}{1 + exp[\mu(P_2 - P_1)]}$$

Source: NREL

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[24] 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.

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

Where *m* is the price slope. With this functional form, if the prices of the two vehicles are identical (P1=P2), 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. (In actuality, the logit function would contain terms representing all vehicle attributes, including price.) If prices are not equal, the influence of the difference on market share depends upon the value of the price slope shown in Figure 31.

Figure 31: Price Slope Equation

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

Source: NREL

Where *b* is the demand elasticity for the market segment, *P* is the price point for the market segment, and *s* is the base market share (in other words, size) of the market segment. Example calculations are presented and discussed in Section 3.1.1 of the 2014 Benefits Report.

Influence of the CTP Support for the Clean Vehicle Rebate Project

The benefits presented in this updated report are therefore similar to those reported previously. Table 15 details the VMT and criteria emission reductions resulting from CTP funds.

Table 15: Summary of VMT and Air Quality Benefits From CTP's Support for CVRP (for BEV, PHEV, and FCEV)

Technology and Case		2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Additional VMT (billions)																						
BEVs	High	-	0.07	0.22	0.40	0.62	0.67	0.74	0.81	0.88	0.96	1.05	1.15	1.25	1.35	1.46	1.58	1.69	1.81	1.92	2.03	2.15
	Low	-	0.04	0.12	0.22	0.34	0.38	0.42	0.46	0.51	0.56	0.61	0.67	0.73	0.79	0.86	0.93	0.99	1.06	1.13	1.19	1.26
PHEVs	High	-	0.08	0.26	0.48	0.74	0.73	0.72	0.71	0.69	0.68	0.66	0.65	0.63	0.61	0.59	0.57	0.55	0.53	0.51	0.49	0.46
	Low	-	0.04	0.14	0.25	0.39	0.38	0.37	0.37	0.36	0.35	0.34	0.34	0.33	0.31	0.30	0.29	0.28	0.26	0.25	0.24	0.22
FCEVs	High	-	-	-	-	0.02	0.03	0.05	0.08	0.10	0.13	0.15	0.18	0.21	0.24	0.28	0.31	0.35	0.39	0.42	0.46	0.50
	Low	-	-	-	-	0.00	0.01	0.01	0.01	0.02	0.02	0.03	0.03	0.04	0.05	0.05	0.06	0.07	0.07	0.08	0.09	0.09
TOTAL	High	-	0.16	0.48	0.87	1.38	1.44	1.51	1.59	1.67	1.76	1.86	1.97	2.09	2.21	2.33	2.46	2.59	2.72	2.85	2.98	3.11
	Low	-	0.09	0.26	0.47	0.74	0.77	0.80	0.85	0.89	0.93	0.98	1.04	1.09	1.15	1.21	1.27	1.33	1.40	1.46	1.52	1.58
ROG Emission Reductions (metric tons)																						
BEVs	High	-	4.0	11.8	21.7	33.8	37.1	40.6	44.4	48.4	52.9	57.7	63.0	68.6	74.4	80.5	86.8	93.0	99.3	105.6	111.8	118.1
	Low	-	2.3	6.6	12.2	19.0	21.0	23.1	25.4	27.9	30.6	33.5	36.7	40.1	43.6	47.2	50.9	54.6	58.3	62.0	65.7	69.4
PHEVs	High	-	3.8	11.7	21.4	33.5	32.9	32.2	31.7	31.2	30.5	29.8	29.1	28.3	27.4	26.6	25.6	24.7	23.7	22.8	21.8	20.9
	Low	-	2.0	6.1	11.1	17.4	17.2	16.8	16.6	16.3	15.9	15.5	15.1	14.6	14.2	13.6	13.0	12.4	11.8	11.2	10.7	10.1
FCEVs	High	-	-	-	-	0.9	1.9	3.0	4.2	5.5	6.9	8.4	9.9	11.6	13.4	15.3	17.3	19.3	21.3	23.3	25.4	27.4
	Low	-	-	-	-	0.2	0.4	0.6	0.8	1.0	1.3	1.6	1.9	2.2	2.5	2.9	3.2	3.6	4.0	4.4	4.8	5.1
TOTAL	High	-	7.8	23.5	43.1	68.2	71.9	75.8	80.3	85.1	90.3	95.9	102.0	108.5	115.3	122.3	129.7	137.0	144.3	151.7	159.0	166.4
	Low	-	4.2	12.7	23.3	36.6	38.5	40.5	42.8	45.2	47.8	50.6	53.7	56.9	60.2	63.7	67.1	70.6	74.1	77.6	81.1	84.6

Technology and Case		**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
NOX Emission Reductions (metric tons)																						
BEVs	High	-	1.1	3.2	5.9	9.2	10.1	11.1	12.1	13.2	14.4	15.7	17.2	18.7	20.3	22.0	23.7	25.4	27.1	28.8	30.5	32.2
	Low	-	0.6	1.8	3.3	5.2	5.7	6.3	6.9	7.6	8.3	9.1	10.0	10.9	11.9	12.9	13.9	14.9	15.9	16.9	17.9	18.9
PHEVs	High	-	0.9	2.8	5.1	8.0	7.8	7.7	7.6	7.4	7.3	7.1	6.9	6.7	6.5	6.3	6.1	5.9	5.6	5.4	5.2	5.0
	Low	-	0.5	1.4	2.7	4.2	4.1	4.0	3.9	3.9	3.8	3.7	3.6	3.5	3.4	3.2	3.1	3.0	2.8	2.7	2.5	2.4
FCEVs	High	-	-	-	-	0.2	0.5	0.8	1.1	1.5	1.9	2.3	2.7	3.2	3.6	4.2	4.7	5.3	5.8	6.4	6.9	7.5
	Low	-	-	-	-	0.0	0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4
TOTAL	High	-	2.0	6.0	11.0	17.4	18.5	19.6	20.8	22.1	23.6	25.1	26.8	28.6	30.5	32.4	34.5	36.5	38.5	40.6	42.6	44.7
	Low	-	1.1	3.3	6.0	9.4	9.9	10.5	11.1	11.8	12.5	13.3	14.1	15.0	15.9	16.9	17.9	18.8	19.8	20.8	21.8	22.7
PM2.5 (Total) Emission Reductions (metric tons)																						
BEVs	High	-	1.0	3.0	5.5	8.5	9.3	10.2	11.2	12.2	13.3	14.5	15.9	17.3	18.7	20.3	21.9	23.4	25.0	26.6	28.2	29.7
	Low	-	0.6	1.7	3.1	4.8	5.3	5.8	6.4	7.0	7.7	8.4	9.2	10.1	11.0	11.9	12.8	13.7	14.7	15.6	16.6	17.5
PHEVs	High	-	0.6	1.8	3.3	5.2	5.1	5.0	4.9	4.8	4.7	4.6	4.5	4.4	4.2	4.1	3.9	3.8	3.7	3.5	3.4	3.2
	Low	-	0.3	0.9	1.7	2.7	2.6	2.6	2.6	2.5	2.5	2.4	2.3	2.3	2.2	2.1	2.0	1.9	1.8	1.7	1.6	1.5
FCEVs	High	-	-	-	-	0.2	0.5	0.8	1.1	1.4	1.7	2.1	2.5	2.9	3.4	3.8	4.4	4.9	5.4	5.9	6.4	6.9
	Low	-	-	-	-	0.0	0.1	0.1	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3
TOTAL	High	-	1.6	4.8	8.8	13.9	14.9	15.9	17.1	18.4	19.7	21.2	22.8	24.5	26.3	28.2	30.1	32.1	34.0	36.0	37.9	39.9
	Low	-	0.9	2.6	4.8	7.5	8.0	8.6	9.2	9.8	10.5	11.2	12.0	12.9	13.8	14.7	15.6	16.6	17.5	18.4	19.4	20.3
CO Emission Reductions (1000 metric tons)																						

Technology and Case		**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
BEVs	High	-	0.2	0.5	0.8	1.3	1.4	1.5	1.7	1.8	2.0	2.2	2.4	2.6	2.8	3.1	3.3	3.6	3.8	4.0	4.3	4.5
	Low	-	0.1	0.3	0.5	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.7	1.8	1.9	2.1	2.2	2.4	2.5	2.7
PHEVs	High	-	0.1	0.3	0.5	0.8	0.8	0.8	0.8	0.8	0.7	0.7	0.7	0.7	0.7	0.6	0.6	0.6	0.6	0.6	0.5	0.5
	Low	-	0.0	0.1	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.2
FCEVs	High	-	-	-	-	0.0	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.6	0.7	0.7	0.8	0.9	1.0	1.0
	Low	-	-	-	-	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2
TOTAL	High	-	0.2	0.7	1.4	2.1	2.3	2.5	2.6	2.8	3.0	3.3	3.5	3.8	4.0	4.3	4.6	4.9	5.2	5.5	5.8	6.1
	Low	-	0.1	0.4	0.7	1.2	1.2	1.3	1.4	1.5	1.6	1.7	1.8	2.0	2.1	2.2	2.4	2.5	2.7	2.8	3.0	3.1

Source: NREL

Increased Availability of Refueling Infrastructure

Refueling station availability for EVSE and hydrogen FCEVs is critical to adopting the new vehicle technology. 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 2014 Benefits Report, each refueling station technology was analyzed by determining a net present cost associated with the customer inconvenience due to limited station availability. This cost penalty was reduced because of CTP project funding, which shifts market dynamics and creates environmental benefits through increased adoption of PHEVs, BEVs, and FCEVs. The EVSE and hydrogen refueling station benefits are evaluated independently in the next sections.

Increased Availability of Electric Vehicle Supply Equipment

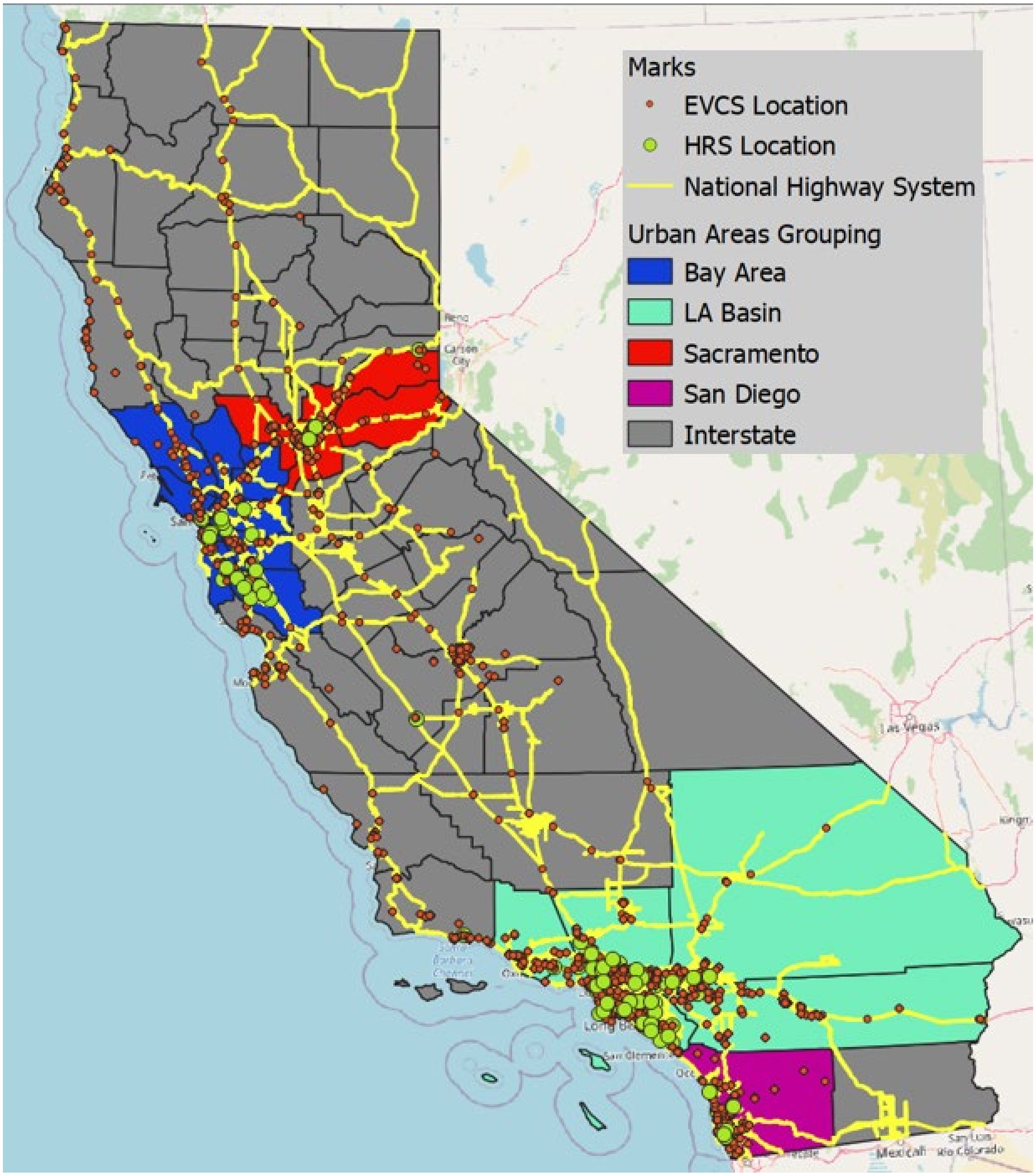
This section of the report attempts to quantify the benefits of EVSE infrastructure and its effect on vehicle adoption and air quality through the lens of market transformation. Table 16 presents the CTP-funded EVSE projects in California’s four major metropolitan areas. EVSE that fall outside these zones have been labeled as Non-Urban. Figure 32 depicts the county groupings used to assign the districts, which include the San Francisco Bay Area, Los Angeles, Sacramento, and the San Diego metro areas.

Table 16: Clean Transportation Program EVSE Stations by City (Through 2021)

Urban Area	Level 2 Public EVSE	Direct Current Fast Chargers
Bay Area	1217	41
Los Angeles	2269	240
Sacramento	599	22
San Diego	1311	47
Non-Urban	749	130

Source: NREL

Figure 32: Metropolitan Area County Grouping



Source: NREL

In the 2014 Benefits Report,[1] the EVSE benefits estimation method relied on a 2013 National Research Council study,[26] which in turn references work by Lin and Greene.[27] Refer to the 2014 Benefits Report for a more thorough description of the LAVE-Trans vehicle choice model, which formed the backbone of estimating the value of public recharging infrastructure. LAVE-Trans uses multiple variables to anticipate future market shares of advanced vehicles such as BEVs and PHEVs, including public charging infrastructure availability. The quantification of the value of EVSE infrastructure has been updated from the LAVE-Trans model and enhanced by using a more holistic methodology to determine value or “Willingness To Pay” (WTP).[28] While the previous methodology relied mainly on the percent of EVSE as compared to gasoline stations, WTP takes into account vehicle range, existing charging infrastructure, energy prices, income, and annual vehicle travel. There are three functions that are used to calculate the WTP for PHEV, BEV intraregional value of EVSE, BEV interregional value of EVSE (DCFC only). These equations are displayed in Figure 33, Figure 34, Figure 35.

Figure 33: PHEV WTP

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

Figure 34: BEV Intraregional Value of EVSE WTP

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

Figure 35: BEV Interregional Value of EVSE WTP

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

Source: NREL, adapted from Greene et al. 2020

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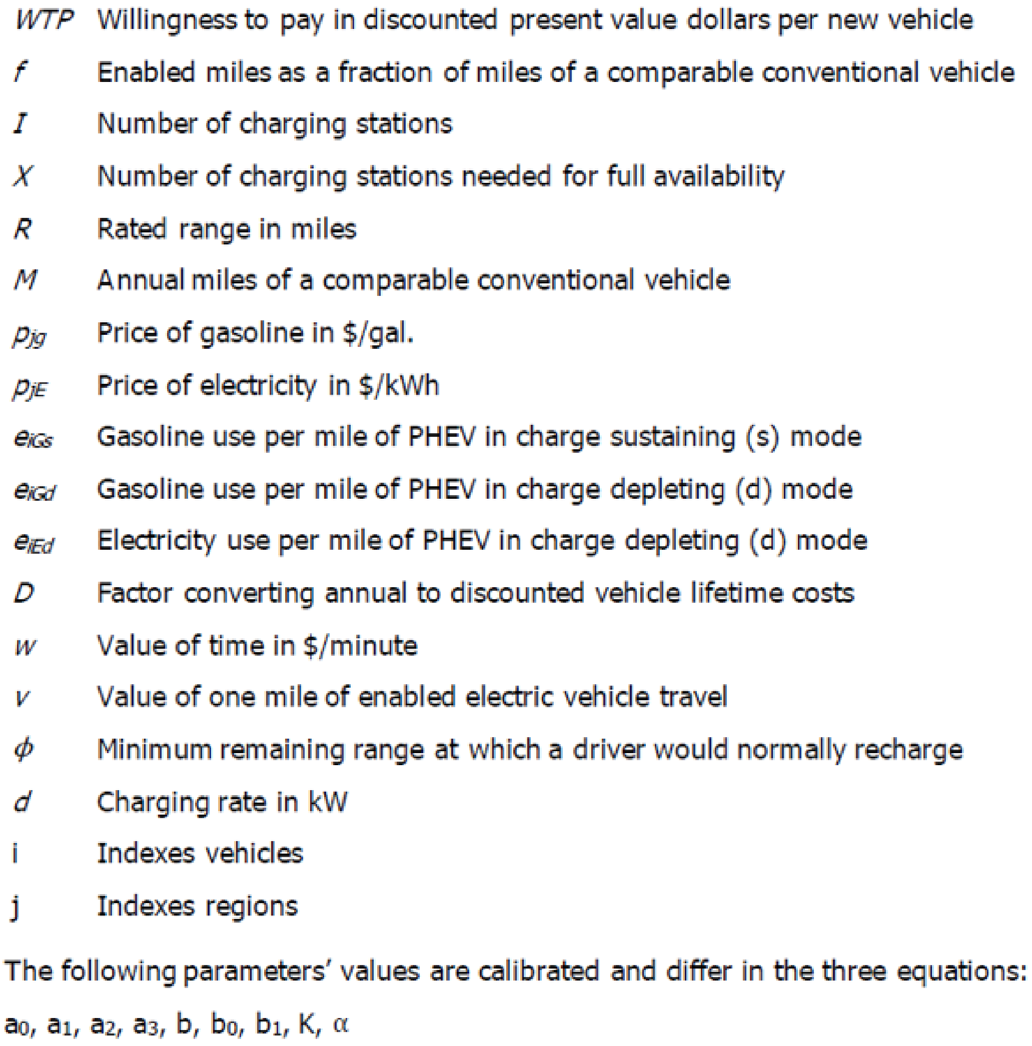
[26] National Research Council. 2013. *Transitions to Alternative Vehicles and Fuels.* The National Academic Press, Washington, D.C.

[27] Lin, Z. and D. Greene. 2011. "Promoting the Market for Plug-in Hybrid and Battery Electric Vehicles: Role of Recharge Availability." *Journal of the Transportation Research Board,* no. 2252, pp. 49-58.

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

The previous equations can most easily be explained in the following way: PHEV WTP is based on annual miles driven and the difference between the cost of electricity and the cost of gasoline as a fuel. The BEV intraregional value is based on the number of chargers in a given geographical area as a proportion of the number of chargers required for full population electrification, this is taken in conjunction with 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 useful in determining their value of charging speed. Finally, all of this is multiplied by a discount rate to account for value over time. A detailed list of the variables and their meaning is shown in Figure 36.

Figure 36: Willingness To Pay Variable Definition List



WTP	Willingness to pay in discounted present value dollars per new vehicle
f	Enabled miles as a fraction of miles of a comparable conventional vehicle
I	Number of charging stations
X	Number of charging stations needed for full availability
R	Rated range in miles
M	Annual miles of a comparable conventional vehicle
p_{jg}	Price of gasoline in \$/gal.
p_{jE}	Price of electricity in \$/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}	Electricity use per mile of PHEV in charge depleting (d) mode
D	Factor converting annual to discounted vehicle lifetime costs
w	Value of time in \$/minute
v	Value of one mile of enabled electric vehicle travel
ϕ	Minimum remaining range at which a driver would normally recharge
d	Charging rate in kW
i	Indexes vehicles
j	Indexes regions

The following parameters' values are calibrated and differ in the three equations:

a_0, a_1, a_2, a_3, b, b_0, b_1, K, α

Source: NREL, adapted from Greene et al. 2020

EVI-Pro 2 was used to determine the number of Public L2 EVSE and DCFC that would be required to service all the previously mentioned urban areas. Using the knowledge of the current number of gasoline stations that are used to service each urban area we can parse the number of EVSE required for full electrification proportionally. EVI-Pro 2 results determine that full electrification required 13,132 level 2 public chargers and 20,884 DCFC

Table 17: Full Electrification Estimates

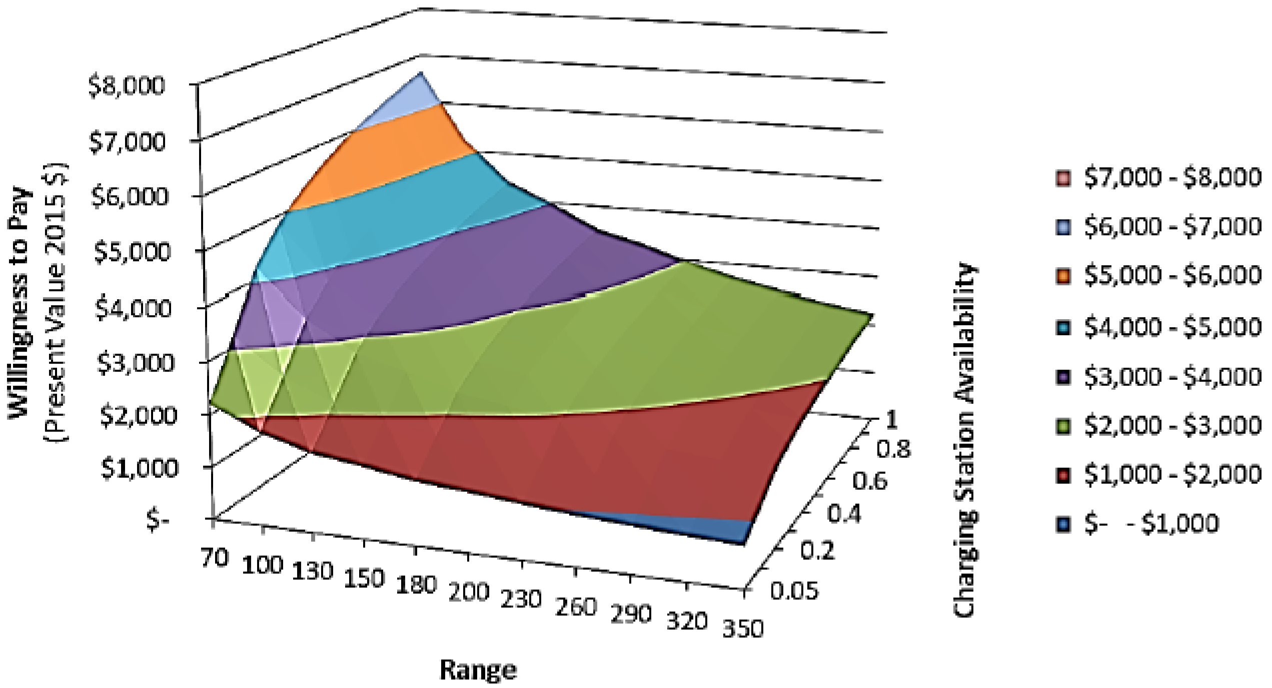
Urban Area	Gas Stations	Full Electrification L2	Full Electrification DCFC
Los Angeles	2813	4467	7104
San Diego	599	951	1513
Bay Area	1164	1849	2940
Sacramento	378	600	955
Non-Urban	3315	5265	8372

Source: NREL

There is an assumption for intraregional travel that DCFC will be utilized 80% of the time and level 2 “convenience charging” will be used 20% of the time. BEV intraregional WTP is similar to intraregional with the exception that vehicle range plays a more important role in the value, and that level 2 is not considered as viable for charging.

After CEC-funded EVSE are grouped into their proper urban areas, data for all other EVSE in the state are brought in and assigned to their 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. Each of these years are then aggregated to see the total value to PEV owners. Figure 35 shows a surface demonstrating the WTP and is a graphical representation of the BEV Intraregional Value of EVSE equation from Figure 34. As BEV range increases, the value of public infrastructure to a BEV owner decreases, since home charging can service more trips throughout the day. This value of infrastructure is similar to charging station availability, as the number of stations get closer to the required amount for full electrification the value to an owner increases less. This is considered when calculating the WTP from CEC funded infrastructure.

Figure 37: Illustration of BEV Willingness to Pay for Public Charging Stations for Intraregional Travel as a Function of Range for a Household with an Annual Income of $80,000



Adapted from Greene et al. 2020

Table 18 presents the parameters used to determine the change in PHEV, BEV and FCEV demand from increased fueling infrastructure availability. Figure 37 shows the WTP for both PHEV and BEV in the four urban areas under study. The reason for the higher observed slopes in WTP for San Diego and Los Angeles is that their number of chargers are still at a lower percent of full electrification than Sacramento and the Bay Area; therefore investment in those regions are more valued by a vehicle owner. These accumulated WTP only include CTP investments; the share of WTP from private and non-CTP investment is accounted for but not included in this figure nor other tables.

Table 18: 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 Light Duty Vehicle	Price Slope
PHEVs				*HEV*	*PHEV (wCVRP)*	
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 (wCVRP)*	
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 (wCVRP)*	
High	-$530	10%	-8.88[29]	$35,717	$47,500	-0.00022
Low	-$530	2.5%	-5	$35,717	$62,500	-0.00014

Source: NREL

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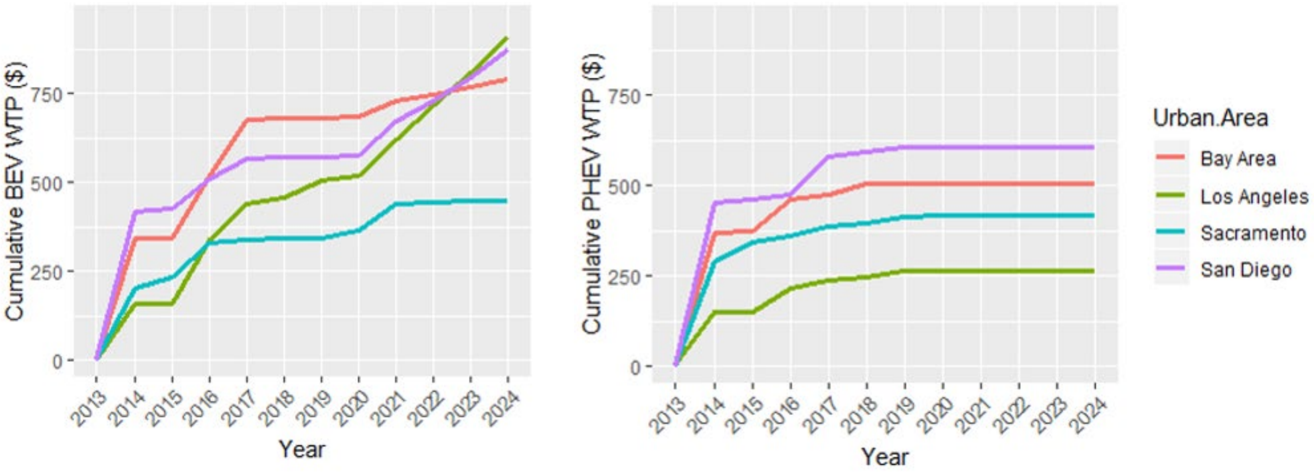
[29] This value deviates from others to align with the long term expected sales by industry set in the 2021 Annual Evaluation of Fuel Cell Electric Vehicle Deployment & Hydrogen Fuel Station Network Development.

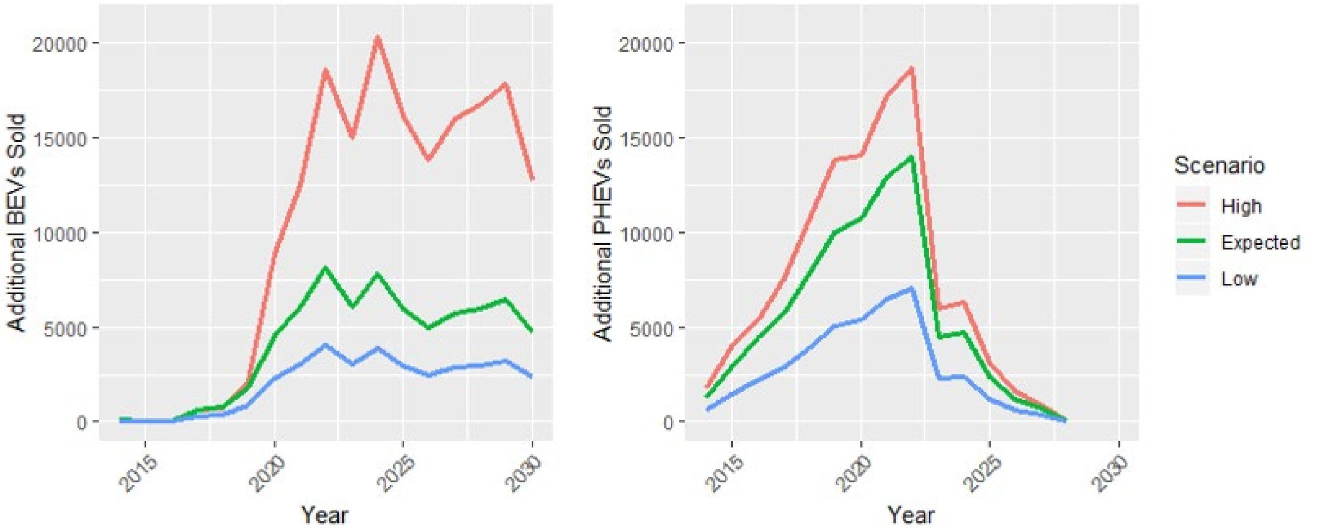
Figure 38: Willingness to Pay for Charging Infrastructure By Vehicle Type and Urban area



Source: NREL

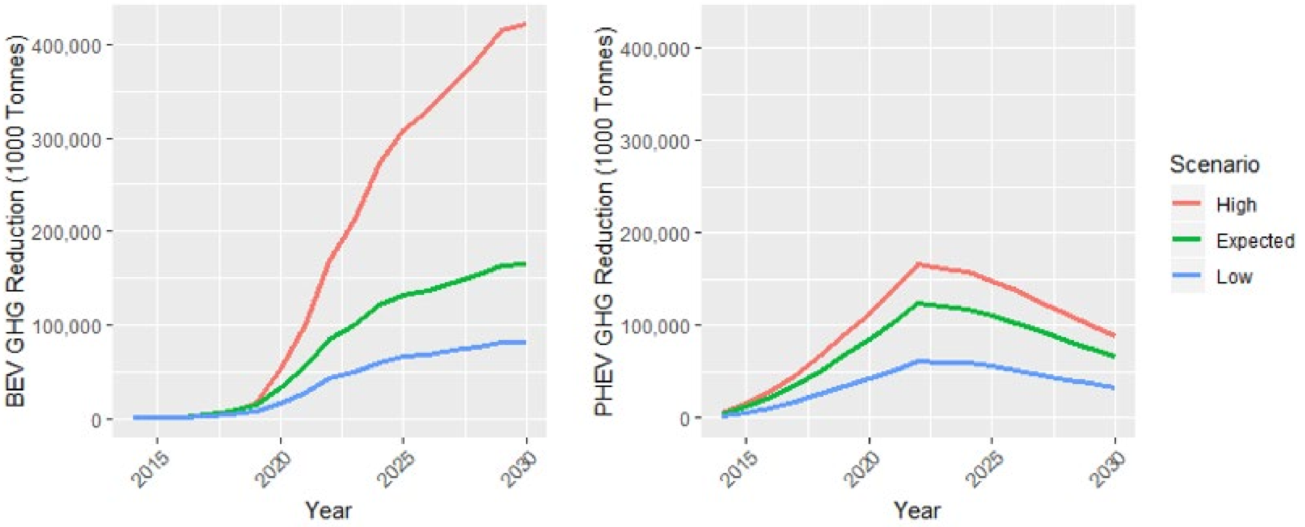
As previously described the WTP values translate into induced vehicles sales, these additional vehicle sales are shown in Figure 39. The results show additional BEVs and PHEVs in circulation as a result of increased EVSE availability from CTP investments. Figure 40 shows the resulting GHG emissions reductions, and Figure 41 the petroleum fuel displaced.

Figure 39: Additional PHEVs and BEVs Deployed due to an Increase in Public EVSE Availability



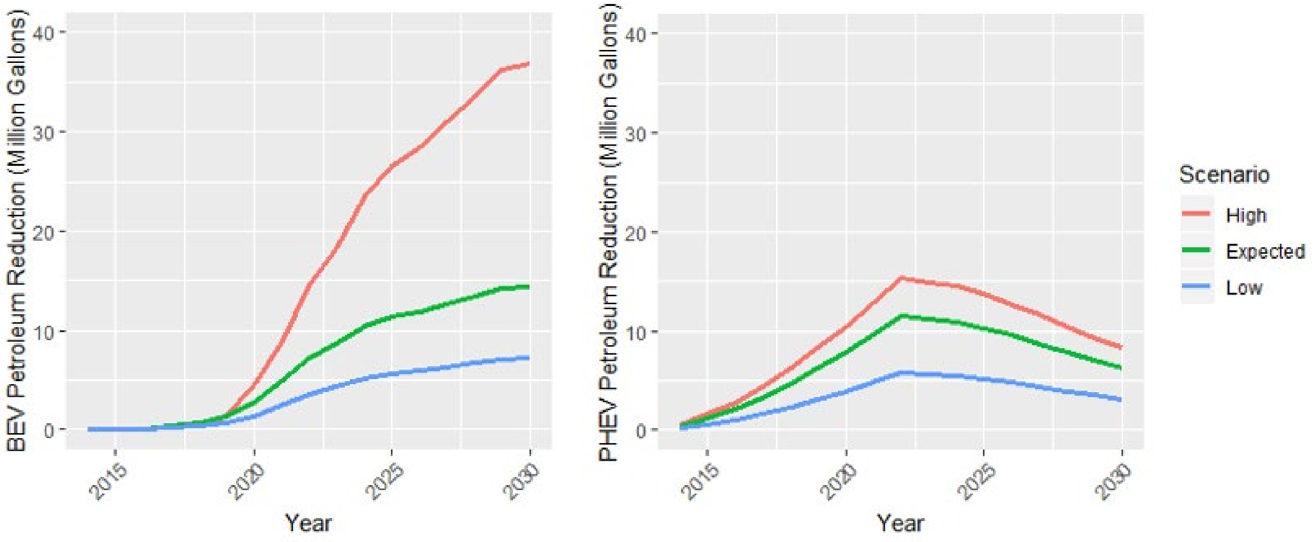
Source: NREL

Figure 40: GHG Reductions from Additional PHEVs and BEVs Deployed due to an Increase in EVSE Availability



Source: NREL

Figure 41: Petroleum Fuel Reductions from Additional PHEVs and BEVs Deployed due to an Increase in EVSE Availability



Source: NREL

Influence of Availability of HRS

As in the 2014 Benefits Report, the authors estimated the availability of the effect of HRSs on consumer behavior.[1] The cost penalties for having a limited availability of HRSs in both urban areas and for intercity travel were estimated using discrete consumer choice surveys and were spatially resolved by specific urban area.[24] The approach used in this 2021 report is the same as was used in the 2017 benefits analysis provided to the CEC.

For urban areas, the authors used natural log curves to estimate the penalties associated when HRS availability is less than 3 percent of the baseline gasoline refueling stations, which provides a conservative estimate of the CTP benefits. The coefficients for the natural log curve function depend on the urban area population and are different for the four urban areas analyzed. The coefficients used were the same as those used in the 2014 Benefits Report although small changes in urban area populations have occurred. Given the coefficients to the natural log curve function, the marginal reduction in the cost penalty from adding the new HRS can be calculated and correlated to a potential market impact.

The project team estimated the intercity cost penalty reductions assuming a linear relationship between HRS availability along interstates and the associated penalty reduction. As in the 2014 Benefits Report, an initial penalty of $2,000 was used and reduced by $333 for each station installed along the interstate. For more information on the calculation method of the urban area and interstate HRS availability penalty reductions, please refer to the 2014 Benefits Report Section 3.3.2. Table 19 shows the baseline penalties for each urban area, reproduced from the 2014 Benefits Report.[1] The 2021 cost penalties change due to new investment in HRS, these cost penalties are summarized in Table 20 and Table 21, respectively.

Table 19: Vehicle Purchase Price Cost Penalty Estimated for HRS Installations in Urban Areas

Urban Area	Reference	Baseline Metro Penalty Before Clean Transportation Program			Interstate	Total
	Stations	**HRS**	**% Stns**	**Penalty**	**Penalty**	**Penalty**
Los Angeles	2,813	7	0.2%	$4,417	$2,000	$6,417
Bay Area	1,164	1	0.1%	$3,654	$2,000	$5,654
San Diego	599	0	*0.02%*	$3,925	$2,000	$5,925
Sacramento	378	0	*0.03%*	$3,499	$2,000	$5,499
Total	4,954	8	0.2%			

Note: Baseline metro penalties for San Diego and Sacramento before the CTP are nominal values shown to reflect penalties near zero availability.

Source: NREL

As seen in Table 20, each station may provide benefits to several urban areas depending on the exact location. As described above, the benefits of each station are assumed to be $333 and applied linearly to each urban area affected since the availability of HRSs is small. Since the benefits contribute to decreasing the baseline $2,000 interstate penalty, the benefit was capped at $2,000 for the San Francisco Bay Area rather than achieving a benefit greater than the theoretical maximum penalty. The Coalinga and Santa Nella stations are expected to provide the greatest reduction in interstate coverage penalties since they are critical connector stations affecting each of the four major urban areas. As seen in 2017 benefits analysis, the San Francisco Bay Area receives the largest benefit from the stations because of its centralized location relative to the HRSs developed.

The method for determining interstate contributing stations was to first find stations that would not be within the four urban area areas. Once these “interstate” stations were determined the distance from every interstate station was measured to the nearest station within an urban area. If the distance was less than 330 miles, that interstate station would give benefits to the specified urban areas.

Table 20: Miles From Interstate HRS to Nearest HRS within a Urban area

Interstate Station	Urban Area			
	Bay Area	Los Angeles	Sacramento	San Diego
Coalinga	109.4	170.1	173.4	275.4
San Ramon	10.5	312.7	60.5	
Santa Barbara	225.0	68.5	301.3	169.0
Santa Clarita	268.3	9.2		114.6
Thousand Oaks	269.7	13.3		115.4
Truckee	137.1		74.4	
Woodside	7.5	304.2	91.7	

Source: NREL

Table 21 summarizes the benefits to consumers in each of the four major urban areas for the HRSs available. Table 21 breaks down the benefits into the metro-related benefits in addition to the interstate benefits that were described in Table 20. The total benefits were then applied to develop the applicable baseline penalty before the CTP notice of proposed awards were implemented. The percentage of gasoline stations is also shown in Table 21, which indicates that the San Francisco Bay Area now tops 2 percent of equivalent HRS station availability, with Los Angeles and San Diego topping 1 percent equivalent.

To translate this reduced market barrier into market transformation benefits, the project team estimated new FCEV sales for a limited consumer market segment because of the availability of HRS infrastructure. Consistent with the 2014 Benefits Report approach, the effect of potential market share impacts was estimated for two early adopter market segments (2.5 percent and 10 percent of light-duty vehicle sales) and at two vehicle price points ($65,000 and $50,000). Furthermore, a $2,500 rebate was used as in the 2014 Benefits Report.

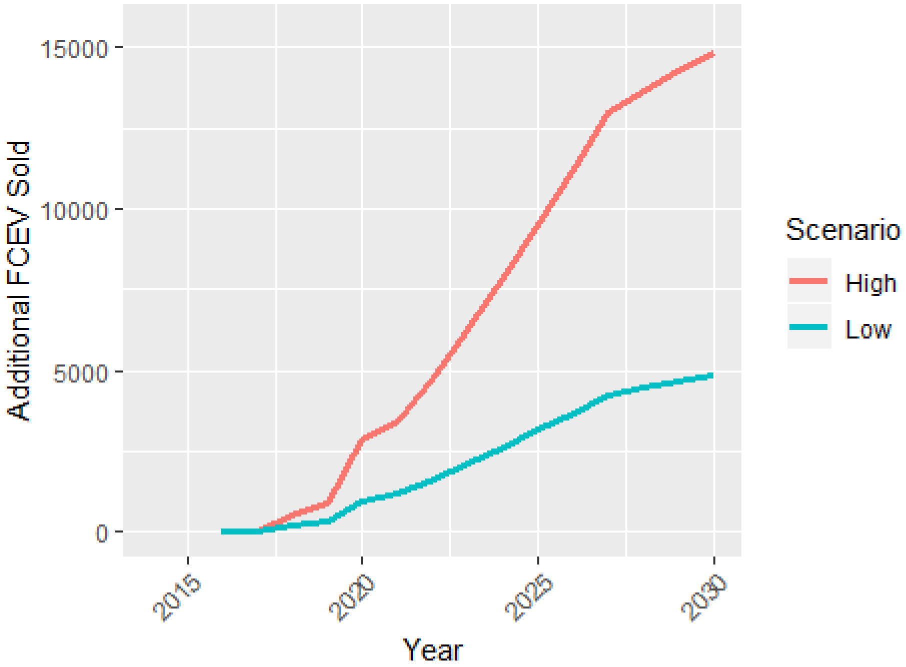
Table 21: Benefits Against HRS Availability Penalties for Three Clean Transportation Program Notice of Proposed Awards

	Baseline				**HRS Stations**							**2021 Benifits**			
Urban Area	Reference Stations	HRS	%Stns	Before Clean Transportation Program Penalty	Interstate Penalty	2014		2017		2021		Metro Benefits	Interstate Benefits	Total Benefits	Remaining Penalty
						HRS	%Stns	HRS	%Stns	HRS	%Stns				
Bay Area	1164	1	0.10%	$3,654	$2,000	14	1.20%	19	1.63%	27	2.32%	$1,786	$2,000	$3,786	$1,868
Los Angeles	2,813	7	0.25%	$4,417	$2,000	32	1.10%	31	1.10%	48	1.71%	$1,547	$2,000	$3,547	$2,870
Sacramento	378	0	0.00%	$3,499	$2,000	1	0.30%	3	0.79%	3	0.79%	$1,422	$1,666	$3,088	$2,411
San Diego	599	0	0.00%	$3,927	$2,000	1	0.20%	3	0.50%	6	1.00%	$1,812	$1,333	$3,145	$2,782
Total	4954	8	0.20%			48	1.00%	56	1.13%	60	1.21%				

Source: NREL

Figure 42 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 1,200 vehicles in 2021 and ramp up to about 3,200 vehicles in 2025 and more than 4,800 by 2030. However, the additional annual FCEV sales for the high case (10 percent market segment and $50,000 per vehicle) begin at just more than 3,400 vehicles per year in 2021 and ramp up to nearly 9,500 FCEVs per year in 2025 and close to 15,000 by 2030. This growth indicates that the price point and market segment are critical to determining the relative effect of the CTP awards for HRS.

Figure 42: Additional FCEVs Sold Due to Installation of HRS



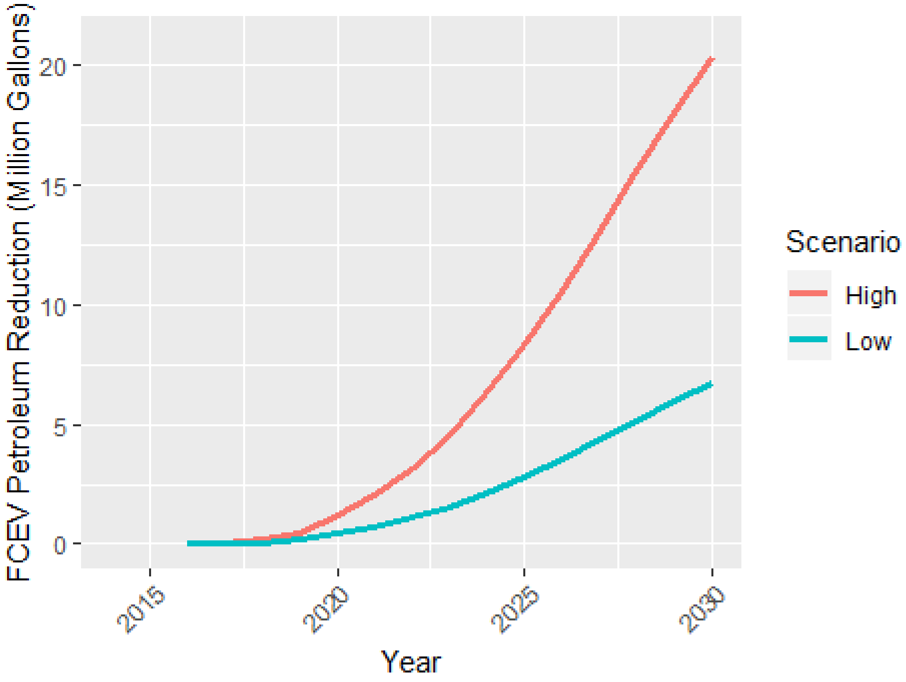
Source: NREL

The resulting petroleum reductions and GHG gas reductions that follow from the increase in FCEV vehicle sales are summarized in Figure 43 and, Figure 44 respectively. The petroleum reduction benefits has an accelerated rate, then at around 2024 increases linearly over the analysis time frame starting at more than 0.7 million GGE in 2021 and increasing to 6.7 million GGE in 2030 for the low case. The high case results in a petroleum reduction of more than 2 million GGE in 2021 and ramps up to more than 20.2 million GGE in 2030. GHG reduction benefits follow a similar pattern and reach a little under 100,000 metric tons (low case) and nearly 300,300 metric tons (high case) of CO_2e by 2030.

These benefits are additive to the expected benefits calculated in Chapter 2. As seen in this analysis, the estimated benefits depend on highly uncertain conditions. Moreover, future estimations of market transformation calculations could be completed with a more rigorous light-duty vehicle consumer choice and stock model such as the Automotive Deployment

Options Projection Tool model.[30] In the Automotive Deployment Options Projection Tool model, the availability of HRS would directly link to differences in price of FCEVs and result in new FCEV sales and VMT predictions leading to new petroleum reduction and GHG reduction benefit estimations. Table 22 summarizes the market transformation benefits from the HRS and EVSE infrastructure supported by the CTP.

Figure 43: Petroleum Fuel Reductions From Additional FCEVs due to Increased HRS Availability



Source: NREL

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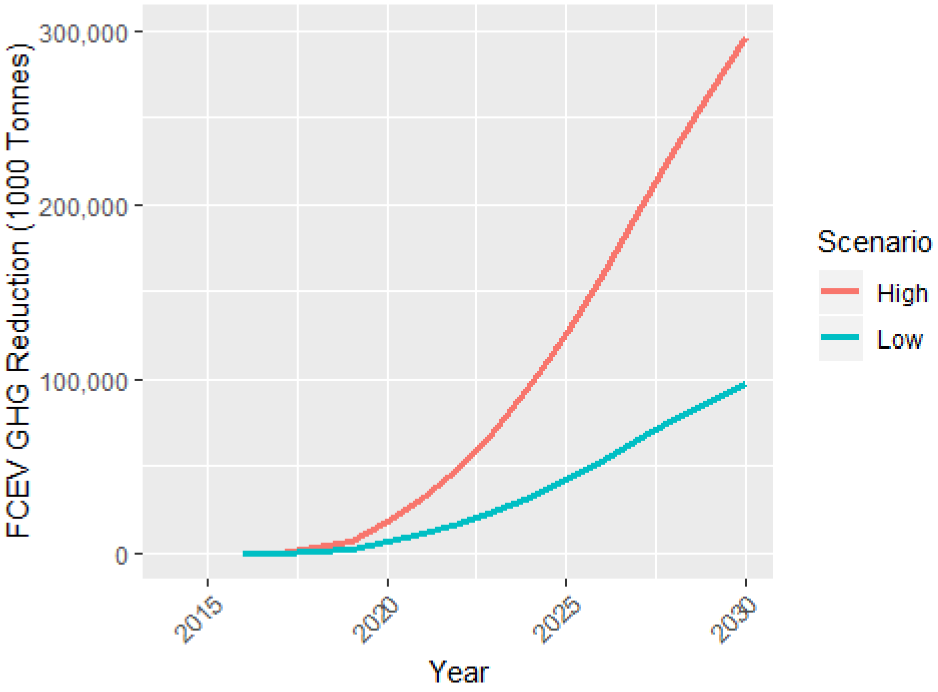
[30] Brooker, A., J. Gonder, and S. Lopp. 2015. "ADOPT: A Historically Validated Light Duty Vehicle Consumer Choice Model," in *SAE 2015 World Congress & Exhibition*, Detroit.

Figure 44: GHG Reductions From Additional FCEVs due to Increased HRS Availability



Source: NREL

Table 22: VMT Enabled from EVSE and HRS Availability

Technology Type	Scenario	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
BEV	High	0.00	0.00	0.00	0.00	0.01	0.03	0.07	0.23	0.44	0.74	0.93	1.20	1.36	1.45	1.57	1.70	1.83	1.85
BEV	Expected	0.00	0.00	0.00	0.00	0.02	0.03	0.06	0.14	0.24	0.37	0.44	0.53	0.58	0.60	0.64	0.68	0.72	0.72
BEV	Low	0.00	0.00	0.00	0.00	0.01	0.02	0.03	0.07	0.12	0.18	0.22	0.27	0.29	0.30	0.32	0.34	0.36	0.36
PHEV	High	0.00	0.04	0.12	0.21	0.34	0.52	0.73	0.93	1.16	1.40	1.36	1.34	1.26	1.17	1.07	0.96	0.86	0.77
PHEV	Expected	0.00	0.03	0.09	0.17	0.26	0.39	0.54	0.70	0.87	1.05	1.02	1.00	0.95	0.87	0.80	0.72	0.64	0.57
PHEV	Low	0.00	0.01	0.04	0.08	0.13	0.20	0.27	0.35	0.44	0.52	0.51	0.50	0.47	0.44	0.40	0.36	0.32	0.29
FCEV	High	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.08	0.14	0.21	0.31	0.42	0.55	0.70	0.86	1.01	1.16	1.30
FCEV	Low	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.05	0.07	0.11	0.14	0.19	0.23	0.29	0.34	0.38	0.43
Total	High	0.00	0.04	0.12	0.21	0.36	0.56	0.83	1.24	1.74	2.35	2.61	2.96	3.17	3.31	3.50	3.67	3.85	3.92
Total	Low	0.00	0.01	0.04	0.09	0.14	0.22	0.32	0.45	0.61	0.78	0.84	0.91	0.95	0.97	1.01	1.03	1.07	1.08

Source: NREL

Table 23: CO2e (1,000 Metric Tons) Reduced from EVSE and HRS Availability

Technology Type	Scenario	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
BEV	High	0.00	0.42	0.58	0.65	3.67	6.75	15.32	52.47	100.91	169.16	212.44	271.95	307.92	328.94	357.06	385.69	415.65	421.20
BEV	Expected	0.00	0.51	0.86	1.12	4.25	7.67	14.75	33.13	55.87	84.51	100.33	121.03	132.14	137.58	145.65	154.16	163.56	164.51
BEV	Low	0.00	0.25	0.43	0.56	2.12	3.83	7.36	16.53	27.89	42.19	50.10	60.45	66.00	68.73	72.77	77.03	81.74	82.22
PHEV	High	0.06	5.79	16.78	29.67	46.03	66.92	91.15	113.08	139.39	166.05	161.50	157.72	148.59	137.03	124.97	112.21	100.39	89.26
PHEV	Expected	0.05	4.20	12.35	23.31	35.46	50.53	67.86	84.76	104.55	124.56	121.14	118.29	111.45	102.77	93.73	84.15	75.28	66.93

PHEV	Low	0.02	2.10	6.17	11.64	17.73	25.27	33.94	42.41	52.33	62.36	60.64	59.21	55.79	51.44	46.91	42.12	37.68	33.50
FCEV	High	0.00	0.00	0.00	0.01	0.28	2.91	6.65	18.70	31.74	48.87	70.24	95.87	125.51	158.59	195.18	230.34	264.25	296.65
FCEV	Low	0.00	0.00	0.00	0.00	0.10	1.12	2.64	6.57	11.02	16.83	24.02	32.57	42.36	53.17	65.00	76.42	87.48	98.06
Total	High	0.06	6.21	17.37	30.33	49.99	76.58	113.13	184.25	272.04	384.09	444.19	525.54	582.02	624.57	677.22	728.23	780.29	807.11
Total	Low	0.02	2.35	6.60	12.20	19.96	30.21	43.94	65.51	91.23	121.38	134.76	152.23	164.15	173.35	184.69	195.58	206.90	213.79

Source: NREL

Table 24: NOx (Metric Tons) Reduced from EVSE and HRS Availability

Technology Type	**Scenario**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
BEV	High	0.00	0.03	0.05	0.06	0.27	0.49	1.09	3.62	7.05	11.99	15.47	20.22	23.71	26.35	29.45	32.57	35.79	37.36
BEV	Expected	0.00	0.04	0.07	0.09	0.32	0.56	1.06	2.34	3.99	6.12	7.48	9.23	10.45	11.33	12.36	13.39	14.46	14.96
BEV	Low	0.00	0.02	0.04	0.05	0.16	0.28	0.53	1.17	1.99	3.05	3.73	4.61	5.22	5.66	6.17	6.69	7.23	7.48
PHEV	High	0.00	0.36	1.02	1.78	2.71	3.86	5.25	6.60	8.22	9.91	10.08	10.25	10.13	9.82	9.39	8.85	8.30	7.75
PHEV	Expected	0.00	0.26	0.75	1.39	2.09	2.92	3.92	4.96	6.17	7.44	7.57	7.69	7.60	7.37	7.05	6.64	6.23	5.81
PHEV	Low	0.00	0.13	0.38	0.69	1.04	1.46	1.96	2.48	3.09	3.73	3.79	3.85	3.80	3.69	3.53	3.32	3.12	2.91
FCEV	High	0.00	0.00	0.00	0.00	0.02	0.19	0.45	1.28	2.22	3.48	5.09	7.08	9.43	12.13	15.18	18.25	21.34	24.43
FCEV	Low	0.00	0.00	0.00	0.00	0.01	0.07	0.18	0.45	0.77	1.20	1.75	2.41	3.19	4.08	5.07	6.07	7.08	8.09
Total	High	0.00	0.40	1.07	1.83	3.00	4.54	6.79	11.50	17.49	25.38	30.64	37.54	43.26	48.30	54.02	59.66	65.43	69.54
Total	Low	0.00	0.15	0.41	0.74	1.21	1.81	2.67	4.10	5.85	7.98	9.27	10.87	12.21	13.42	14.77	16.08	17.43	18.48

Source: NREL

Table 25: PM2.5 (Metric Tons) Reduced from EVSE and HRS Availability

Technology Type	Scenario	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
BEV	High	0.00	0.01	0.01	0.01	0.05	0.09	0.16	0.45	0.72	0.95	1.07	1.27	1.37	1.52	1.62	1.72	1.82	1.82
BEV	Expected	0.00	0.01	0.02	0.02	0.06	0.10	0.16	0.30	0.42	0.51	0.55	0.61	0.63	0.68	0.70	0.72	0.75	0.74
BEV	Low	0.00	0.00	0.01	0.01	0.03	0.05	0.08	0.15	0.21	0.26	0.27	0.30	0.32	0.34	0.35	0.36	0.37	0.37
PHEV	High	0.00	0.02	0.06	0.11	0.18	0.27	0.39	0.46	0.50	0.50	0.51	0.52	0.53	0.54	0.54	0.53	0.52	0.50
PHEV	Expected	0.00	0.01	0.04	0.08	0.14	0.20	0.29	0.35	0.38	0.38	0.38	0.39	0.39	0.40	0.40	0.40	0.39	0.37
PHEV	Low	0.00	0.01	0.02	0.04	0.07	0.10	0.14	0.17	0.19	0.19	0.19	0.19	0.20	0.20	0.20	0.20	0.19	0.19
FCEV	High	0.00	0.00	0.00	0.00	0.00	0.03	0.06	0.15	0.22	0.27	0.33	0.41	0.49	0.62	0.73	0.83	0.92	1.00
FCEV	Low	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.05	0.08	0.09	0.11	0.14	0.17	0.21	0.24	0.28	0.30	0.33
Total	High	0.00	0.03	0.07	0.12	0.23	0.38	0.61	1.06	1.44	1.72	1.91	2.20	2.38	2.68	2.88	3.07	3.25	3.32
Total	Low	0.00	0.01	0.03	0.05	0.10	0.16	0.25	0.37	0.47	0.54	0.58	0.64	0.68	0.75	0.79	0.83	0.87	0.89

Source: NREL

Influence of Investments in Vehicle Production

Total benefits resulting from investments in vehicle production processes (including components and general manufacturing) are updated based upon changes in CTP funding allocated in each category. The method of calculation is the same as in the 2014 Benefits Report. Induced sales from EV component manufacturing (learning reduces costs, some of those cost reductions are passed onto the consumer as a lower purchase price) are much lower than in the 2014 report (roughly 2000-4000 sales/yr) primarily due to smaller advanced vehicle sales forecast (CA Vision 2.1 vs NREL assumptions in 2014 report). Table 26 presents details on projected induced sales and criteria emission reductions. As of the 2021 benefits report all manufacturing expected benefits have been moved to the market transformation section for aggregation.

Table 26: Induced Vehicle Sales Due to Manufacturing and Component Demonstrations

Technology Type	Scenario	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
ELE	High	11	18	9	6	41	41	71	152	170	199	220	235	245	251	253	253	250	246
ELE	Low	11	18	9	6	41	41	71	152	170	199	220	235	245	251	253	253	250	246
PHEV	High	73	128	168	205	212	247	258	240	254	260	260	261	261	261	261	261	261	261
PHEV	Low	73	128	168	205	212	247	258	240	254	260	260	261	261	261	261	261	261	261

Source: NREL

Table 27: CO2e Reductions due to Manufacturing and Component Demonstrations

Technology Type	Scenario	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
BEV	High	65	163	192	199	378	529	779	1354	1939	2568	3211	3849	4459	5020	5530	5983	6377	6708
BEV	Low	65	163	192	199	378	529	779	1354	1939	2568	3211	3849	4459	5020	5530	5983	6377	6708
PHEV	High	234	603	1012	1441	1812	2186	2509	2762	3017	3255	3467	3652	3813	3948	4061	4155	4232	4294
PHEV	Low	234	603	1012	1441	1812	2186	2509	2762	3017	3255	3467	3652	3813	3948	4061	4155	4232	4294

Source: NREL

Table 28: NOx Reductions due to Manufacturing and Component Demonstrations

Technology Type	Scenario	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
BEV	High	0.006	0.014	0.017	0.018	0.031	0.043	0.061	0.102	0.146	0.195	0.247	0.301	0.356	0.410	0.461	0.509	0.554	0.595
BEV	Low	0.006	0.014	0.017	0.018	0.031	0.043	0.061	0.102	0.146	0.195	0.247	0.301	0.356	0.410	0.461	0.509	0.554	0.595
PHEV	High	0.015	0.039	0.065	0.091	0.114	0.137	0.158	0.177	0.196	0.214	0.230	0.245	0.257	0.269	0.278	0.287	0.294	0.301
PHEV	Low	0.015	0.039	0.065	0.091	0.114	0.137	0.158	0.177	0.196	0.214	0.230	0.245	0.257	0.269	0.278	0.287	0.294	0.301

Source: NREL

Table 29: PM2.5 Reductions due to Manufacturing and Component Demonstrations

Technology Type	Scenario	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
BEV	High	0.0014	0.0032	0.0037	0.0037	0.0060	0.0076	0.0096	0.0137	0.0166	0.0181	0.0198	0.0215	0.0230	0.0257	0.0271	0.0282	0.0291	0.0298
BEV	Low	0.0014	0.0032	0.0037	0.0037	0.0060	0.0076	0.0096	0.0137	0.0166	0.0181	0.0198	0.0215	0.0230	0.0257	0.0271	0.0282	0.0291	0.0298
PHEV	High	0.0009	0.0024	0.0041	0.0062	0.0082	0.0104	0.0125	0.0137	0.0143	0.0141	0.0140	0.0139	0.0138	0.0141	0.0140	0.0139	0.0138	0.0138
PHEV	Low	0.0009	0.0024	0.0041	0.0062	0.0082	0.0104	0.0125	0.0137	0.0143	0.0141	0.0140	0.0139	0.0138	0.0141	0.0140	0.0139	0.0138	0.0138

Source: NREL

Next-Generation Fuel Production Facilities

Each of the 58 fuel production projects funded by the CTP are evaluated as "next-generation facilities" for the associated potential to incur market transformation benefits. As in the 2014 Benefits Report, next-generation benefits are estimated by adjusting survey capacity values with two factors: (1) scaling factor, scaling up the capacity of small production plants to larger next-generation plant capacities, and (2) volume-to-funding ratio, scaling down next-generation plant capacities if the CTP funds provided are small relative to the survey capacity estimate. Brief explanations of these two adjustments are provided below. Refer to the 2014 Benefits Report for an explanation of how the adjustment factors are estimated.

1. **Scaling factor.** Market transformation benefits are accrued for the volume of fuel provided by one additional next-generation plant. Fuel production projects with relatively small survey capacity estimates (less than 1 million gallons per year) are scaled by the scaling factor to estimate larger next-generation plants. Projects with relatively large survey capacity estimates (greater than 1 million gallons per year) are assumed deployed a second time at the same scale. In the high benefits case, 100 percent of the volume from next-generation plants is allocated and the plants are installed three years after completion of the initial facility supported by the CTP. In the low benefits case, 25 percent of the volume is allocated, and plants are installed five years after completion of the initial facility, assuming that some delay in market uptake occurs and only some of the technological progress achieved in the initial facility translates to the next-generation facility.

2. **Volume-to-funding ratio.** The authors assume market transformation benefits decline as the ratio of survey production capacity (gallons per year) to funding support provided (dollars from CTP) begins to exceed 1 gallon per year per dollar. The percentage of facility capacity allocated declines exponentially as this ratio increases, reaching 5 percent for a plant having a ratio of roughly 100 gallons per year per dollar. Given this parameter definition, the adjustment results in a significant reduction (for example, greater than 1 percent) for seven projects. For all projects with a ratio less than 1 gallon per year per dollar, the volume-to-funding ratio is unity, resulting in no change to the plant size determined using the scaling factor.

Table 30 summarizes fuel production projects, including awardee and survey output volume. Table 31 presents adjustment factors and resulting output volumes used to determine market transformation benefits.

Table 30: Summary of Fuel Production Projects and Annual Outputs

Project #	Awardee	Fuel Product	Displacing	Funding ($M)	Output	Units
ARV-10-003	Sacramento Municipal Utility District (SMUD)	Biomethane	Natural Gas	1.79	0.00	DGE
ARV-10-023	G4 Insights, Inc.	Biomethane	Natural Gas	1.23	0.00	DGE
ARV-10-026	Clean World Partners, LLC	Biomethane	Natural Gas	1.32	424500.00	DGE
ARV-10-040	Northstate Rendering Co Inc.	Biomethane	Natural Gas	5.46	46588.20	DGE
ARV-10-052	CR&R Incorporated	Biomethane	Natural Gas	4.52	890670.00	DGE
ARV-10-053	Pixley Biogas LLC	Biomethane	Natural Gas	4.67	205304.00	DGE
ARV-11-021	Clean World	Biomethane	Natural Gas	6.00	405150.20	DGE
ARV-12-031	Blue Line Transfer, Inc.	Biomethane	Natural Gas	2.59	95369.10	DGE
ARV-12-033	Mendota Bioenergy, LLC	Biomethane	Natural Gas	2.71	0.00	DGE
ARV-14-028	City of San Mateo	Biomethane	Natural Gas	2.45	1215.20	DGE
ARV-15-054	City of Petaluma	Biomethane	Natural Gas	3.00	75000.00	DGE
ARV-15-067	Quantitative BioSciences, Inc.	Biomethane	Natural Gas	2.00	100000.00	DGE
ARV-16-027	City of Manteca	Biomethane	Natural Gas	3.00	140000.00	DGE
ARV-17-008	California Bioenergy, LLC	Biomethane	Natural Gas	3.05	500000.00	DGE
ARV-17-009	County Sanitation Districts of Los Angeles County	Biomethane	Natural Gas	2.50	761000.00	DGE
ARV-17-019	Anaheim Energy LLC	Biomethane	Natural Gas	3.08	880000.00	DGE
ARV-17-036	Monterey Regional Waste Management District	Biomethane	Natural Gas	1.82	520785.00	DGE
ARV-17-036	Monterey Regional Waste Management District	Biomethane	Natural Gas	1.82	520785.00	DGE

ARV-18-020	City of Roseville Biofuels	Biomethane	Natural Gas	3.00	161900.00	DGE
ARV-18-021	California Grinding, Inc.	Biomethane	Natural Gas	3.00	2400000.00	DGE
ARV-18-023	The Southern California Gas Company (SoCalGas)	Biomethane	Natural Gas	3.00	528.00	DGE
ARV-18-024	Technology & Investment Solutions LLC	Biomethane	Natural Gas	2.00	40000.00	DGE
ARV-18-028	Technikon, LLC	Biomethane	Natural Gas	1.13	73000.00	DGE
ARV-18-029	Rialto Bioenergy LLC	Biomethane	Natural Gas	2.92	1620000.00	DGE
ARV-19-075	Five Points Pipeline LLC	Biomethane	Natural Gas	3.54	2536172.00	DGE
ARV-10-022	East Bay Municipal Utility District	Diesel Substitutes	Biodiesel	1.00	1160000.00	DGE
ARV-10-024	Biodiesel Industries	Diesel Substitutes	Biodiesel	0.89	9180000.00	DGE
ARV-10-027	Cal Poly Corporation (Cal Poly State University, San Luis Obispo)	Diesel Substitutes	Biodiesel	0.25	1200.00	DGE
ARV-10-043	Agricultural Waste Solutions, Inc.	Diesel Substitutes	Biodiesel	0.66	0.00	DGE
ARV-10-047	Solazyme, Inc.	Diesel Substitutes	Biodiesel	1.27	0.00	DGE
ARV-11-015	New Leaf Biofuel LLC	Diesel Substitutes	Biodiesel	0.51	1260000.00	DGE
ARV-11-016	Springboard Biodiesel	Diesel Substitutes	Biodiesel	0.76	0.00	DGE
ARV-11-019	SacPort Biofuels Corporation	Diesel Substitutes	Biodiesel	5.00	14100.00	DGE
ARV-12-035	Buster Biofuels LLC	Diesel Substitutes	Biodiesel	2.64	0.00	DGE
ARV-13-007	Crimson Renewable Energy, LP	Diesel Substitutes	Biodiesel	5.00	7379000.00	DGE
ARV-13-008	American Biodiesel, Inc. (dba Community Fuels)	Diesel Substitutes	Biodiesel	4.90	5000000.00	DGE
ARV-13-052	Crimson Renewable Energy, LP	Diesel Substitutes	Biodiesel	5.00	4600000.00	DGE

ARV-14-022	AltAir Fuels, LLC	Diesel Substitutes	Biodiesel	5.00	10000000.00	DGE
ARV-14-024	American Biodiesel, Inc. (dba Community Fuels)	Diesel Substitutes	Biodiesel	4.18	5860000.00	DGE
ARV-15-008	University of California, Davis; Regents of the University of California	Diesel Substitutes	Biodiesel	0.57	377440.90	DGE
ARV-15-011	San Diego State University Research Foundation	Diesel Substitutes	Biodiesel	0.28	0.00	DGE
ARV-16-018	SJV Biodiesel, LLC	Diesel Substitutes	Biodiesel	3.60	5000000.00	DGE
ARV-16-020	New Leaf Biofuel LLC	Diesel Substitutes	Biodiesel	3.79	7000000.00	DGE
ARV-17-014	Crimson Renewable Energy, LP	Diesel Substitutes	Biodiesel	4.46	12000000.00	DGE
ARV-18-018	Oberon Fuels, Inc.	Diesel Substitutes	Biodiesel	2.88	830000.00	DGE
ARV-18-023	The Southern California Gas Company (SoCalGas)	Diesel Substitutes	Biodiesel	3.00	110889.00	DGE
600-09-017	California Alternative Energy and Advanced Transportation Financing Authority	Gasoline Substitutes	Ethanol	6.00	0.00	DGE
ARV-10-017	Great Valley Energy, LLC	Gasoline Substitutes	Ethanol	1.91	0.00	DGE
ARV-10-028	Mendota Advanced Bioenergy Beet Cooperative	Gasoline Substitutes	Ethanol	1.50	0.00	DGE
ARV-10-031	Aemetis Advanced Products Keyes, Inc.	Gasoline Substitutes	Ethanol	0.00	0.00	DGE
ARV-10-033	Calgren Renewable Fuels, LLC	Gasoline Substitutes	Ethanol	0.00	0.00	DGE
ARV-11-018	EdeniQ	Gasoline Substitutes	Ethanol	3.90	0.00	DGE
ARV-14-021	Calgren Renewable Fuels, LLC	Gasoline Substitutes	Ethanol	1.10	2300000.00	DGE
ARV-14-026	Pacific Ethanol Development, LLC	Gasoline Substitutes	Ethanol	1.50	1796609.00	DGE

ARV-14-027	Aemetis Advanced Products Keyes, Inc.	Gasoline Substitutes	Ethanol	2.04	1577023.00	DGE
ARV-15-009	Altex Technologies Corporation	Gasoline Substitutes	Ethanol	1.00	0.00	DGE
ARV-15-017	West Biofuels, LLC	Gasoline Substitutes	Ethanol	1.00	0.00	DGE
ARV-18-019	Aemetis Advanced Products Keyes, Inc.	Gasoline Substitutes	Ethanol	5.00	7516181.00	DGE

Source: NREL

Table 31: Fuel Production Project Adjustments and Market Transformation Output in 2030

Project #	Fuel Product	Volume to Funding Ratio	Market Transformation: Petroleum Reduction (GGE/DGE)	Market Transformation: GHG Reduction (thousand metric tons CO2e)
ARV-10-040	Biomethane	0.009	0.140	0.717
ARV-10-052	Biomethane	0.197	2.672	13.916
ARV-10-053	Biomethane	0.044	0.616	3.161
ARV-11-021	Biomethane	0.068	1.215	6.237
ARV-12-031	Biomethane	0.037	0.286	1.490
ARV-12-033	Biomethane	0.000	0.000	0.000
ARV-14-028	Biomethane	0.000	0.004	0.015
ARV-15-054	Biomethane	0.025	0.225	1.063
ARV-15-067	Biomethane	0.050	0.300	1.388
ARV-16-027	Biomethane	0.047	0.420	7.076
ARV-17-008	Biomethane	0.164	1.500	8.152
ARV-17-009	Biomethane	0.304	2.283	7.157
ARV-17-019	Biomethane	0.286	2.640	10.583
ARV-17-036	Biomethane	0.287	1.562	0
ARV-18-020	Biomethane	0.054	0.486	2.194
ARV-18-021	Biomethane	0.800	4.793	39.923
ARV-18-023	Biomethane	0.000	0.002	0.006

ARV-18-023	Biomethane	0.000	0.333	1.298
ARV-18-024	Biomethane	0.020	0.120	1.924
ARV-18-028	Biomethane	0.065	0.219	2.176
ARV-18-029	Biomethane	0.555	3.240	63.003
ARV-19-075	Biomethane	0.717	5.069	94.121
ARV-11-015	Diesel Substitutes	2.461	2.216	13.249
ARV-11-019	Diesel Substitutes	0.003	0.042	0.128
ARV-12-035	Diesel Substitutes	0.000	0.000	0.000
ARV-13-007	Diesel Substitutes	1.476	14.324	83.470
ARV-13-008	Diesel Substitutes	1.019	9.939	27.539
ARV-13-052	Diesel Substitutes	0.920	9.168	59.636
ARV-14-022	Diesel Substitutes	2.000	18.517	105.223
ARV-14-024	Diesel Substitutes	1.401	11.435	74.382
ARV-15-008	Diesel Substitutes	0.658	1.132	2.761

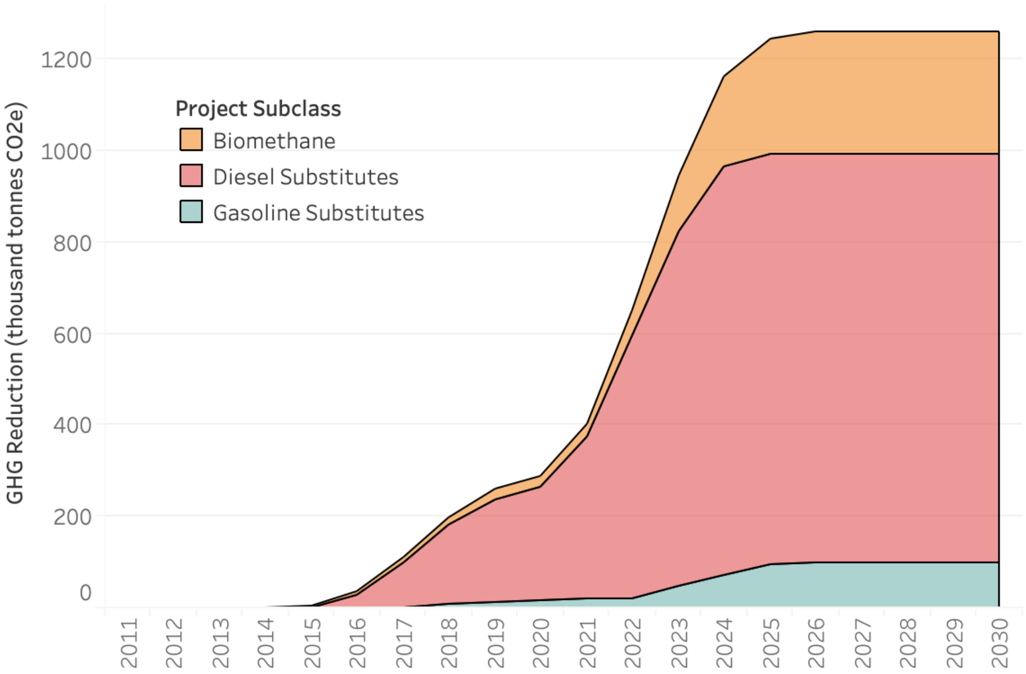
ARV-15-011	Diesel Substitutes	0.000	0.000	0.000
ARV-16-018	Diesel Substitutes	1.389	9.764	56.945
ARV-16-020	Diesel Substitutes	1.848	13.162	218.509
ARV-17-014	Diesel Substitutes	2.689	20.536	234.844
ARV-18-018	Diesel Substitutes	0.289	2.490	16.148
ARV-18-023	Diesel Substitutes	0.037	0.002	0.006
ARV-18-023	Diesel Substitutes	0.037	0.333	1.298
600-09-017	Gasoline Substitutes	0.000	0.000	0.000
ARV-10-028	Gasoline Substitutes	0.000	0.000	0.000
ARV-11-018	Gasoline Substitutes	0.000	0.000	0.000
ARV-14-021	Gasoline Substitutes	2.084	4.221	7.696
ARV-14-026	Gasoline Substitutes	1.201	3.546	5.543

ARV-14-027	Gasoline Substitutes	0.774	3.150	4.789
ARV-15-009	Gasoline Substitutes	0.000	0.000	0.000
ARV-15-017	Gasoline Substitutes	0.000	0.000	0.000
ARV-18-019	Gasoline Substitutes	1.503	14.561	81.377

Source: NREL

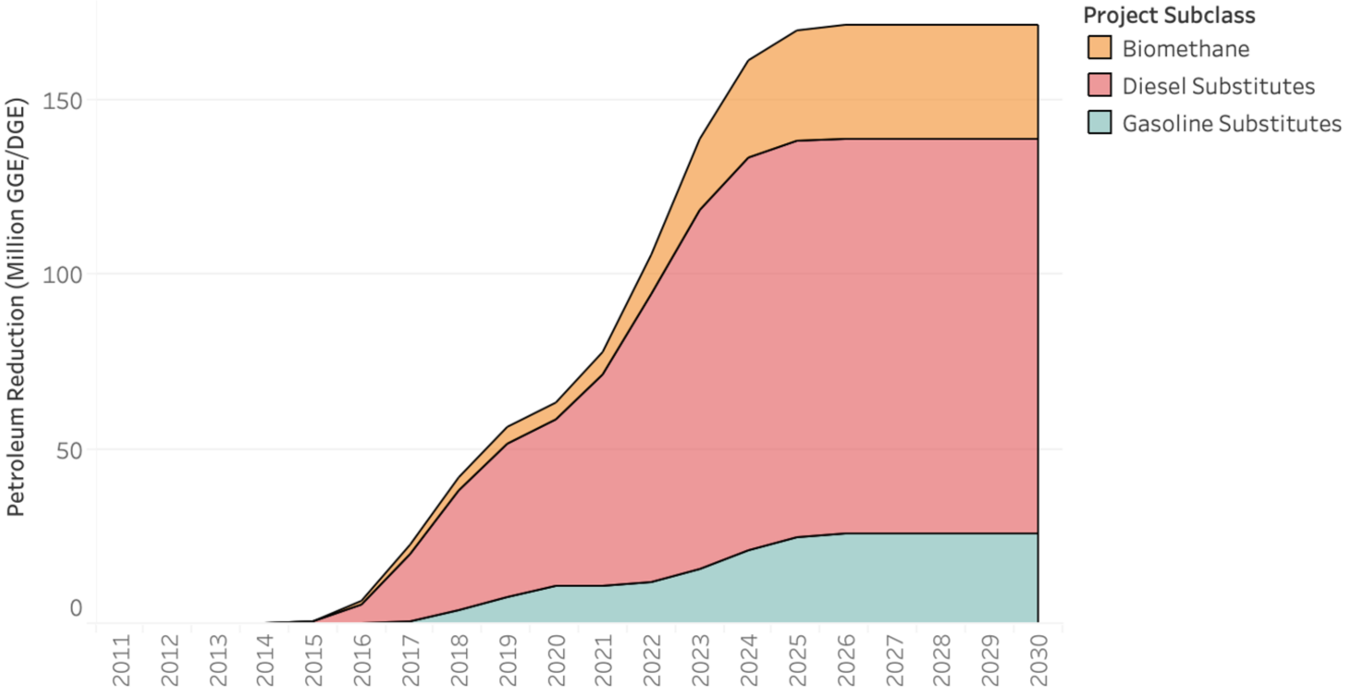
Graphic representation is shown in Figure 44 and Figure 45 by fuel type. Seen below, diesel substitutes seem to provide the majority of GHG and petrol fuel reduction benefit and benefits level out starting in 2025. Numerical values for these results are shown by year in Table 32.

Figure 45: Market Transformation Fuel Production GHG Reductions



Source: NREL

Figure 46: Market Transformation Fuel Production Petrol Fuel Reductions



Source: NREL

Table 32: GHG and Petroleum Reductions From Next Generation Biofuel Estimates

Fuel Category (Petroleum Reduction in millions DGE/GGE)	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Biomethane	0.04	0.53	1.48	3.10	4.67	5.78	6.17	7.91	14.66	25.27	35.16	40.02	41.01	41.01	41.01	41.01	41.01
Diesel Substitute	0.00	0.35	6.67	24.00	42.41	54.92	59.69	75.29	103.07	128.06	140.81	141.31	141.32	141.32	141.32	141.32	141.32
Gasoline Substitute	0.00	0.00	0.00	0.70	4.79	9.34	13.19	13.65	14.42	19.74	25.81	31.11	31.85	31.85	31.85	31.85	31.85
TOTAL	**0.04**	**0.88**	**8.15**	**27.80**	**51.87**	**70.04**	**79.05**	**96.84**	**132.15**	**173.07**	**201.79**	**212.43**	**214.19**	**214.19**	**214.19**	**214.19**	**214.19**

Fuel Category (GHG Reduction in $MMTCO_2e$)	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Biomethane	0.2	2.7	7.6	16.0	24.1	29.9	31.9	36.3	69.0	151.9	247.7	314.9	332.0	332.0	332.0	332.0	332.0
Diesel Substitute	0.0	2.1	34.9	122.6	216.1	279.1	306.8	443.7	716.3	973.4	1113.4	1117.6	1117.7	1117.7	1117.7	1117.7	1117.7
Gasoline Substitute	0.0	0.0	0.0	1.2	7.9	15.4	21.8	22.5	26.8	56.6	90.5	120.1	124.3	124.3	124.3	124.3	124.3
TOTAL	**0.2**	**4.8**	**42.5**	**139.8**	**248.2**	**324.5**	**360.5**	**502.5**	**812.1**	**1181.9**	**1451.7**	**1552.6**	**1573.9**	**1573.9**	**1573.9**	**1573.9**	**1573.9**

Source: NREL

Next-Generation Advanced Truck Demonstrations

While the same general analytic approach has been used to estimate market transformation benefits for next-generation advanced truck demonstrations, updated project-level data have been used to revise the effectiveness of investments by project type. These updated values are provided in Table 33 in units of total medium-duty trucks or heavy-duty trucks deployed per million dollars invested and by project category: electric-drive, natural gas, and gasoline substitute truck demonstrations. The most significant updates, compared to the 2017 benefits analysis, are for the electric-drive low case and the natural gas low and high cases.

Table 33: Key Low and High Case Assumptions for Next-Generation Advanced Truck Benefits

	Low Case	High Case
Electric-drive	The ratio of future fuel reductions per dollar of project funding is assumed equal to the ratio determined for vehicles supported through Hybrid and Zero-Emission Truck and Bus Voucher Incentive Project. • 357,200 DGE reduced and $4.0M invested is 89 DGE per $1000	The ratio of future fuel reductions per dollar of project funding is based upon the CLEAN truck program, which involves many types of electric-drive projects. • 3,000 medium-duty trucks and 4,500 heavy-duty trucks deployed and $18M invested is 852 medium-duty truck and 373 heavy-duty trucks per $1.0M invested (when allocated on a fuel use basis)
Natural Gas	The number of additional vehicles deployed per dollar of project funding is assumed to be equal to the lowest ratio among all natural gas demo projects (GTI, ARV-11-029), multiplied by a factor of 10 to account for scale-up in production. • 25 additional medium-duty trucks, scaled to 250 medium-duty truck, and $4.56M invested is 55 medium-duty truck per $1.0M invested	The number of additional vehicles deployed per dollar of project funding is assumed equal to the mid-range ratio among all natural gas demo projects (Kenworth, ARV-09-012) (The ratio for the third natural gas project is considered too high). • 500 additional heavy-duty trucks and $1.46M invested is 343 heavy-duty trucks per $1.0M invested
Gasoline Substitute	The number of additional vehicles deployed is equal to 10% of the first year of market adoption potential suggested in survey data. • 1,000 additional medium-duty truck and $0.607M invested is 1,647 medium-duty truck per $1.0M invested	The number of additional vehicles deployed is equal to 100% of the first year of market adoption potential suggested in survey data. • 10,000 additional medium-duty truck and $0.607M invested is 16,474 medium-duty truck per $1.0M invested

Source: NREL

The revised effectiveness ratios for fuel displaced, GHGs reduced, and additional vehicles deployed per dollar invested are indicated by project category in Table 34, along with the resulting ratio of dollars per metric ton of CO_2e reduced, which is used as a check on the low and high effectiveness ratios. Assumptions about future fuel economy and miles driven per year are unchanged from the 2014 Benefits analysis: 7.3 miles per gallon (mpg) and 19,800 miles per year for Classes 4-6 and 4.0 mpg and 98,000 miles per year for Classes 7-8.

Table 34: Relative Effectiveness Metric for Advanced Truck Projects

Category and Case	**Fuel Displaced**	**GHGs Displaced**	**Additional Trucks per Funding**	**Additional Trucks per Funding**	**Carbon Metric**
	DGE/$1000/yr	kg CO_2e/$ per year	medium-duty truck/$M	heavy-duty truck/$M	$/Metric Ton CO_2e
M-HD Electric Trucks					
High	463	6.2	852	373	13.54
Low	89	0.5	164	72	70.42
low/high (percent)	*19%*	*9%*	*19%*	*19%*	-
M-HD Gaseous Trucks					
High (heavy-duty trucks)	8,504	39.6	-	343	2.10
Low (medium-duty truck)	149	0.6	55	-	147.47
low/high (percent)	*2%*	*1%*	*16%*	-	-
MD Gasoline Sub Trucks					
High	44,725	18.0	16,474	-	4.62
Low	4,473	1.8	1,647	-	46.25
low/high (percent)	*10%*	*10%*	*10%*	-	-

Source: NREL

Table 35: Benefit Results by Advanced Truck Category and Case

Advanced Truck Category and Case	Number of Vehicles	New Fuel Economy	Fuel Use per Vehicle	Fuel Use Total	Petrol Fuel Reduced	GHG Reduction
	(additional)	(MPDGE)	(DGE/yr/veh)	(M DGE/yr)	(M DGE/yr)	(MMTCO$_2$e/yr)
Electric medium-duty truck						
High	21,509	9.1	2,172	46.71	11.68	0.155
Low	4,136	9.1	2,172	8.98	2.25	0.030
Electric heavy-duty trucks						
High	32,263	4.2	23,570	106.06	40.02	0.532
Low	6,205	4.2	23,570	106.06	7.70	0.102
Gaseous medium/heavy-duty trucks						
High (heavy-duty trucks)	10,101	4.3	22,555	227.81	250.60	1.1683
Low (medium-duty truck)	1,615	7.3	2,715	4.38	4.38	0.0167
Gasoline Sub medium-duty truck						
High	10,000	7.3	2,715	27.15	27.15	0.0109
Low	1,000	7.3	2,715	2.71	2.71	0.0011

Source: NREL

Table 36: Benefit Results by Advanced Truck Category and Case

Metric	Units	Scenario	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Petroleum Reduction	M Gallons	High	0	0.2	0.3	4.2	8.2	12.2	22.6	42.1	63.1	84	111.3	151.8	199.7	247.4	282.5	291.4	291.4	290.8	290.8
Petroleum Reduction	M Gallons	Low	0	0	0.1	0.2	0.3	0.4	0.7	2.1	3.7	5.4	7.3	8.9	11.9	14.8	17.4	19.1	19.1	19	19
CO2	thousand metric tons CO2e	High	0	2	4	24	44	65	121	207	313	418	558	792	1124	1454	1715	1834	1834	1826	1826
CO2	thousand metric tons CO2e	Low	0	0	1	1	2	3	6	14	26	37	51	66	100	134	164	187	187	185	185
NOx	metric tons	High	0.00	0.00	0.00	0.05	0.10	0.15	0.27	0.51	0.77	1.02	1.35	1.84	2.42	3.00	3.43	3.53	3.53	3.53	3.53
NOx	metric tons	Low	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.03	0.05	0.07	0.09	0.11	0.14	0.18	0.21	0.23	0.23	0.23	0.23
PM25	metric tons	High	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.03	0.03	0.03	0.03
PM25	metric tons	Low	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Source: NREL

Summary of Market Transformation Benefits

The sections above review results for each of the market transformation influences and various applicable project categories. Most influences have been evaluated with high and low estimates for fuel use and GHG reductions out to 2030. Table 37 and Table 38 summarize the market transformation impacts on GHG reductions and petroleum reductions, respectively.

Table 37: Summary of Market Transformation Petroleum Reductions

Category	Units	Scenario	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Fuel Production	M Gallons	High	0	0	0	1	7	22	41	55	62	76	104	137	159	168	169	169	169	169	169
Fuel Production	M Gallons	Low	0	0	0	0	2	6	10	14	16	19	26	34	40	42	42	42	42	42	42
Next Gen Trucks	M Gallons	High	0	0	0	4	8	12	23	42	63	84	111	152	200	247	283	291	291	291	291
Next Gen Trucks	M Gallons	Low	0	0	0	0	0	0	1	2	4	5	7	9	12	15	17	19	19	19	19
Perceived Vehicle Price Reductions	M Gallons	High	0	0	1	2	3	5	7	10	16	24	33	38	45	49	52	55	59	63	65
Perceived Vehicle Price Reductions	M Gallons	Low	0	0	0	1	1	2	3	5	7	10	14	16	18	19	20	21	23	24	24
Vehicle Cost Reduction	M Gallons	High	82	113	138	124	112	104	96	89	91	96	104	114	123	132	138	143	146	147	146
Vehicle Cost Reduction	M Gallons	Low	38	53	64	58	53	49	46	44	44	44	45	46	48	50	52	54	56	58	60

Source: NREL

Table 38: Summary of Market Transformation GHG Reductions

Category	Units	Scenario	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Fuel Production	M Gallons	High	0	0	0	3	32	105	188	247	275	390	634	926	1137	1217	1235	1235	1235	1235	1235
Fuel Production	M Gallons	Low	0	0	0	1	8	26	47	62	69	97	159	232	284	304	309	309	309	309	309
Next Gen Trucks	M Gallons	High	0	2	4	24	44	65	121	207	313	418	558	792	1124	1454	1715	1834	1834	1826	1826

Next Gen Trucks	M Gallons	Low	0	0	1	1	2	3	6	14	26	37	51	66	100	134	164	187	187	185	185
Perceived Vehicle Price Reductions	M Gallons	High	0	0	6	17	30	50	77	113	184	273	387	449	531	586	625	674	721	772	803
Perceived Vehicle Price Reductions	M Gallons	Low	0	0	3	7	13	22	34	51	82	119	164	185	213	230	242	258	273	289	296
Vehicle Cost Reduction	M Gallons	High	856	1184	1447	1303	1176	1093	1025	993	1125	1315	1532	1706	1887	2051	2176	2262	2334	2351	2367
Vehicle Cost Reduction	M Gallons	Low	395	547	667	606	552	527	510	524	630	757	886	964	1052	1136	1204	1259	1320	1347	1393

Source: NREL

Table 39: Summary of Market Transformation NOx Reductions

Category	Units	Scenario	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Next Gen Trucks	M Gallons	High	0	1.9	3.8	51.5	99.2	148.2	273.6	510.1	765	1019	1349	1840	2421	3000	3425	3534	3534	3526	3526
Next Gen Trucks	M Gallons	Low	0	0.4	0.7	1.9	3.1	4.5	8.4	25.1	45.4	65.4	88.1	107.3	143.9	180	211	231.9	231.9	230.4	230.4
Perceived Vehicle Price Reductions	M Gallons	High	0	0	0.4	1.1	1.8	3	4.5	6.8	11.5	17.6	25.6	31	37.9	43.6	48.4	53.8	59.2	64.9	69.2
Perceived Vehicle Price Reductions	M Gallons	Low	0	0	0.2	0.4	0.8	1.4	2.1	3.2	5.3	7.9	11	13	15.5	17.4	19.1	21	22.8	24.7	26
Vehicle Cost Reduction	M Gallons	High	63.5	89.7	111.3	108	109.5	117.8	133.8	162.4	235.1	331.4	426.7	488.9	547.9	612.2	658.7	703.5	744	765.6	790.6
Vehicle Cost Reduction	M Gallons	Low	30.5	43	53.3	52.3	55.6	65.5	83.3	114	184.8	277	366.7	422.5	474.8	532.8	574.1	615	653.1	673.6	699

Source: NREL

Table 40: Summary of Market Transformation PM2.5 Reductions

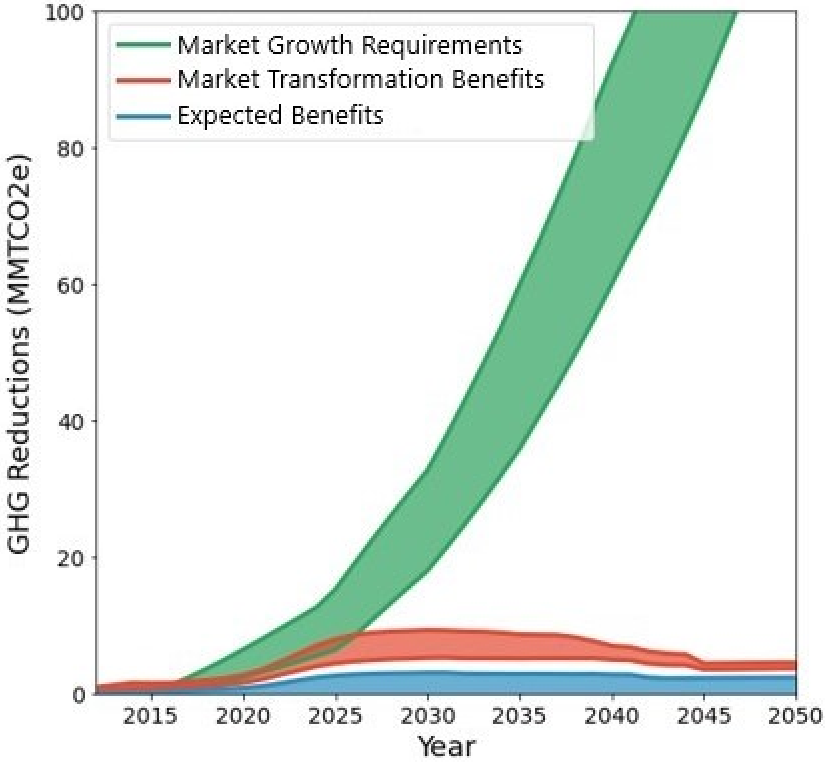
Metric	Units	Scenario	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Next Gen Trucks	metric tons	High	0	0	0	0.4	0.7	1.1	2	3.7	5.5	7.3	9.7	13.2	17.4	21.5	24.6	25.4	25.4	25.3	25.3
Next Gen Trucks	metric tons	Low	0	0	0	0	0	0	0.1	0.2	0.3	0.5	0.6	0.8	1	1.3	1.5	1.7	1.7	1.7	1.7
Perceived Vehicle Price Reductions	metric tons	High	0	0	0	0.1	0.1	0.2	0.4	0.6	1.1	1.4	1.7	1.9	2.2	2.4	2.7	2.9	3	3.2	3.3
Perceived Vehicle Price Reductions	metric tons	Low	0	0	0	0	0.1	0.1	0.2	0.3	0.5	0.7	0.8	0.9	0.9	1	1.1	1.1	1.2	1.2	1.3
Vehicle Cost Reduction	metric tons	High	5.3	7.9	9.8	9.7	9.5	9.5	9.6	11.2	14.9	19.1	21.5	23.5	25.4	27.2	29.2	30.7	32.1	33.5	34.7
Vehicle Cost Reduction	metric tons	Low	3.6	5	6.1	5.9	5.7	5.7	5.8	7.4	10.7	14.5	16.6	18.4	20.2	21.9	23.7	25.3	26.9	28.4	30

Source: NREL

CHAPTER 4: Carbon Market Growth Requirements

Carbon market growth indicates the magnitude of GHG reductions required to meet the long-term goal of an 80 percent reduction in California's transportation GHG emissions below 1990 levels by 2050. These reduction requirements help place CTP benefits into a long-term, statewide perspective. As was the case in the 2014 Benefits Guidance report,[1] these reduction requirements are based upon the CARB *Vision for Clean Air* study. While this study indicated potential combinations of vehicles and fuels required to meet an 80 to 90 percent GHG reduction goal within the transportation sector, the overall reductions are shown in aggregate as the green-shaded area in Figure 46, reaching 100 million metric tons (MMT) CO_2e reduced by 2040–2045. By comparison, the sum of expected (blue) and high market transformation (red) GHG reductions associated with CTP projects funded to date approaches 14.7 MMT CO_2e by around 2030, which falls within the bounds of the near-term reduction trajectory indicated (green). This long-term perspective suggests that CTP projects are making substantial contributions in the near term. GHG reductions occurring as a result of a wide range of policy and market influences must be an order of magnitude greater within the next 25 to 30 years to reach the 80 percent reduction goal.

Figure 47: Near- and Long-Term Perspective on GHG Reductions



Source: NREL

CHAPTER 5:
Summary and Recommendations

This chapter summarizes estimated benefits and market transformation benefits. Furthermore, recommendations are summarized to improve future benefit estimation efforts for Clean Transportation Program (CTP) projects.

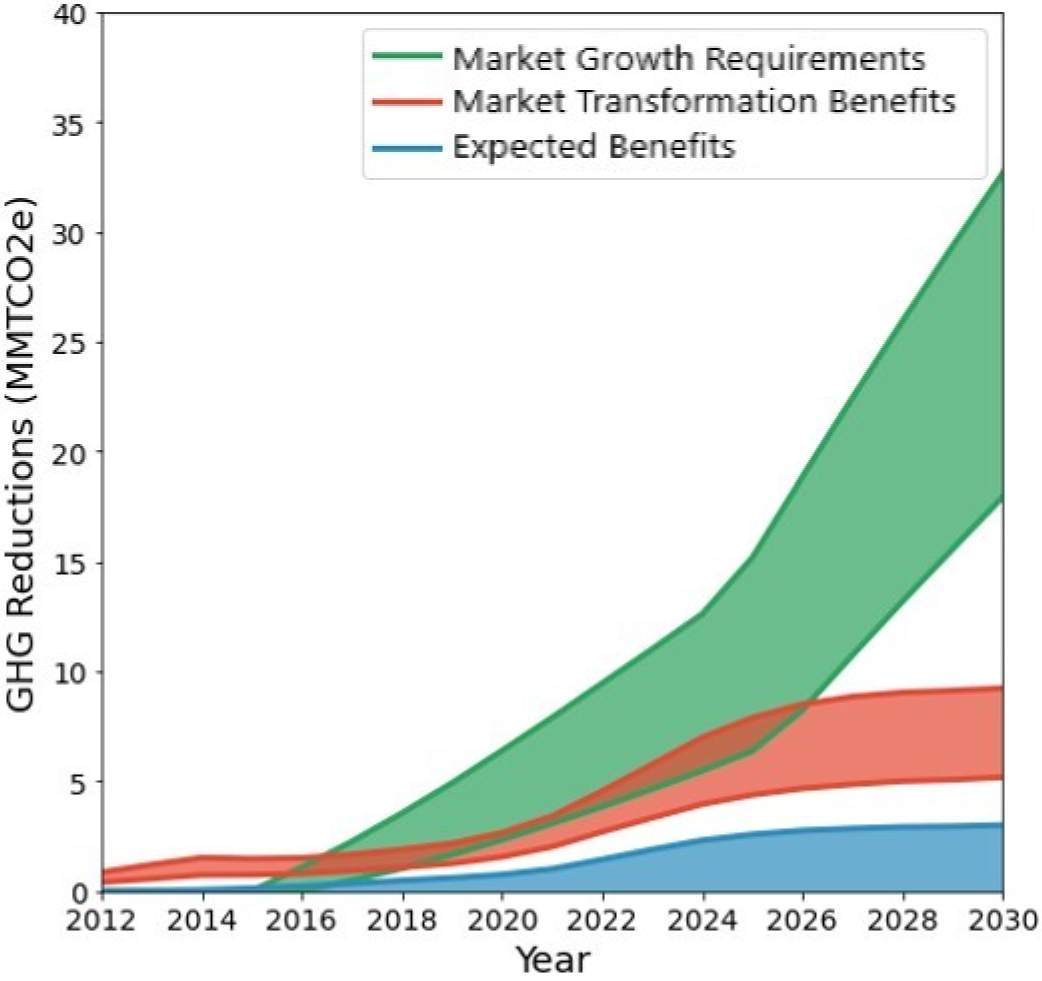
Summary of Benefit Estimation Results

This report focused on evaluating CTP project benefits from direct displacement of carbon-based transportation technologies (expected benefits) and from accelerating the market adoption of alternative, low-carbon transportation technologies (market transformation benefits). Required carbon market growth trajectories were also estimated to identify trends required to approach California's long-term GHG reduction goals, such as an 80 percent reduction in GHG emissions by 2050 relative to 1990.

Table 41 and Table 42 summarize the petroleum and GHG reduction benefits, respectively, for each benefit category analyzed. By 2030, expected benefit GHG reductions are estimated to reach 1.42 million metric tons per year from the 261 million GGE per year of petroleum displaced due to the new transportation technologies adopted. The market transformation impacts are estimated between 1.19 million and 5.47 million metric tons of GHG reduction per year and 160 million to 803 million GGE per year reduction in petroleum use in 2030. The expected benefits increase steadily until 2020, begin to plateau by 2022 and remain largely unchanged through 2025 with the fuel production and vehicles projects contributing the most to the benefits. In 2025, the fuel production benefits are reduced because of the accounting change discussed earlier to increase conservatism on the benefits estimates. The market transformation benefits follow a similar trend as the expected benefits, ramping up early as projects come on-line until 2024, when it begins to plateau in the low and high cases.

Figure 48 summarizes the results, overlaying the required carbon market growth trends with the expected and market transformation benefits. It shows that total estimated CTP benefits with the *high scenario* market transformation benefits case produce significant progress toward meeting California's GHG reduction goals. However, the *low scenario* market transformation case results in GHG reduction trends just below the required market growth reduction trend. Figure 47 highlights that CTP project expected benefits alone will not meet the market growth requirements and in the low market transformation benefit case, the GHG reductions may not reach the required California GHG reductions goals. Compared to the 2014 Benefits Report, the total benefits are higher but shifted out in time due to the new project funding. This comparison emphasizes the importance of continued investment and progress in advanced transportation technologies.

Figure 48: GHG Reductions From Expected Benefits, Market Transformation Benefits, and Required Carbon Market Growth



Source: NREL. "Market Growth Benefits" refers to the required carbon market growth trajectory needed to meet the state's long-term GHG reduction goal.

Table 41: Summary of Petroleum Reductions (Million Gallons per Year) for All Benefit Categories

Benefit Category	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Expected Benefits																		
Fuel Production	0.0	0.0	0.3	3.3	11.3	21.1	28.5	32.1	39.0	52.5	68.2	79.2	83.4	84.1	84.1	84.1	84.1	84.1
Fueling Infrastructure	2.0	7.2	15.7	24.7	31.4	36.8	40.9	44.1	46.6	51.1	58.1	68.9	80.2	90.1	95.3	97.5	99.3	101.3
Vehicles	0.5	1.5	2.7	4.0	5.4	7.4	11.4	20.6	32.1	42.9	48.4	53.3	58.2	60.5	62.1	63.3	63.1	63.6
Total	2.5	8.7	18.6	31.9	48.1	65.3	80.8	96.8	117.7	146.5	174.7	201.4	221.9	234.7	241.5	244.9	246.4	249.0
Market Transformation Benefits																		
High																		
Fuel Production	0	0	0.7	6.6	21.9	40.7	54.8	62.1	76.4	104.4	136.8	159.4	167.8	169.2	169.2	169.2	169.2	169.2
Next Gen Trucks	0.2	0.3	4.2	8.2	12.2	22.6	42.1	63.1	84	111.3	151.8	199.7	247.4	282.5	291.4	291.4	290.8	290.8
Perceived Vehicle Price Reductions	0	0.6	1.6	2.9	4.7	7	10.2	16.1	23.6	33.2	38.1	44.8	49	51.8	55.4	59	63	65.3
Vehicle Cost Reduction	113	137.7	124.2	111.9	103.5	95.5	88.8	90.8	96.3	104.4	113.6	123.1	131.7	138.4	143.1	145.9	147	146.2
Total	113.2	138.6	130.7	129.6	142.3	165.8	195.9	232.1	280.3	353.3	440.3	527	595.9	641.9	659.1	665.5	670	671.5
Low																		

Benefit Category	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Fuel Production	0	0	0.2	1.6	5.5	10.2	13.7	15.5	19.1	26.1	34.2	39.8	41.9	42.3	42.3	42.3	42.3	42.3
Next Gen Trucks	0	0.1	0.2	0.3	0.4	0.7	2.1	3.7	5.4	7.3	8.9	11.9	14.8	17.4	19.1	19.1	19	19
Perceived Vehicle Price Reductions	0	0.2	0.7	1.2	2.1	3.1	4.6	7.2	10.3	14.1	15.8	18	19.4	20.2	21.4	22.5	23.7	24.3
Vehicle Cost Reduction	52.6	63.9	58	52.5	49.2	46	43.6	43.8	44.2	45	46.3	48	49.9	51.8	53.8	55.8	57.8	59.7
Total	52.6	64.2	59.1	55.6	57.2	60	64	70.2	79	92.5	105.2	117.7	126	131.7	136.6	139.7	142.8	145.3
Required Carbon Market Growth																		
High	0.0	0.0	0.0	113.4	225.7	337.7	445.6	665.4	901.4	1151.5	1417.2	1695.3	1959.5	2236.1	2518.5	2808.6	3109.0	3380.9
Low	0.0	0.0	0.0	0.0	44.0	88.4	129.9	237.2	358.4	492.1	643.0	804.2	957.3	1120.5	1292.4	1476.4	1670.9	1865.3

Source: NREL

Table 42: Summary of GHG Reductions for All Benefit Categories

Benefit Category	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Expected Benefits																		
Fuel Production	0.0	0.2	4.1	36.3	118.3	209.4	272.9	302.5	423.9	692.5	1009.7	1239.6	1321.2	1338.3	1338.3	1338.3	1338.3	1338.3
Fueling Infrastructure	11.6	37.8	72.7	106.4	129.8	152.1	170.1	185.7	202.5	241.8	305.3	404.5	506.5	599.0	647.9	673.7	690.5	714.9
Vehicles	2.4	7.2	13.9	24.2	37.5	58.3	98.5	200.0	318.7	434.3	492.9	558.3	616.7	659.5	685.6	718.2	717.9	739.6
Total	14.1	45.1	90.7	166.9	285.6	419.7	541.4	688.2	945.2	1368.7	1807.9	2202.3	2444.4	2596.9	2671.9	2730.2	2746.8	2792.9
Market Transformation Benefits High																		
High																		
Fuel Production	0	0.2	3.3	31.7	105.3	188.2	246.5	275.3	389.6	634.2	926.1	1137.4	1217.4	1234.5	1234.5	1234.5	1234.5	1234.5
Next Gen Trucks	2.1	4.1	24	43.9	65.3	121	206.9	313.1	418.1	558.2	791.9	1124.4	1454.4	1715	1834	1834	1825.7	1825.7
Perceived Vehicle Price Reductions	0.1	6.2	17.4	30.3	50	76.6	113.1	184.2	273	386.9	448.8	530.7	585.7	625	673.5	720.8	771.8	803
Vehicle Cost Reduction	1184.3	1447.1	1302.8	1175.5	1093.2	1025.2	993.2	1125	1315.4	1532.4	1706	1887.4	2050.9	2175.5	2262.1	2334.2	2351.2	2367.4
Total	1186.5	1458	1347.5	1281.4	1313.8	1411	1559.7	1897.6	2396.1	3111.7	3872.8	4679.9	5308.4	5750	6004.1	6123.5	6183.2	6230.6
Low																		
Fuel Production	0	0	0.8	7.9	26.3	47	61.6	68.8	97.4	158.6	231.5	284.3	304.4	308.6	308.6	308.6	308.6	308.6
Next Gen Trucks	0.4	0.8	1.4	2.1	3	5.8	13.7	25.5	37.1	50.6	65.8	100	133.8	163.8	186.7	186.7	185.1	185.1

Benefit Category	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Perceived Vehicle Price Reductions	0	2.6	7	12.8	22.1	34.1	51.3	82.1	119.2	163.7	185	212.8	230.3	242.2	257.6	272.7	288.7	296.1
Vehicle Cost Reduction	546.6	667.3	605.7	551.9	526.7	510.4	524.3	629.9	757	886.1	964	1051.7	1135.9	1204.3	1258.5	1320.3	1346.5	1392.6
Total	547	670.7	614.9	574.7	578.1	597.3	650.9	806.3	1010.7	1259	1446.3	1648.8	1804.4	1918.9	2011.4	2088.3	2128.9	2182.4
Required Carbon Market Growth																		
High	-	-	-	1,085	2,252	3,544	4,919	6,397	7,903	9,462	11,015	12,614	15,189	18,851	22,440	25,935	29,351	32,661
Low	-	-	-	-	487.6	1,030	1,653	2,333	3,081	3,842	4,650	5,481	6,375	8,241	10,739	13,188	15,575	17,944

Source: NREL

Table 43: Summary of NOx Reductions (Metric Tons per Year) for All Benefit Categories

Benefit Category	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Expected Benefits																		
Fuel Production	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fueling Infrastructure	0.0	0.5	1.3	2.1	2.7	3.3	4.0	4.3	5.0	7.2	11.6	17.4	24.5	30.4	33.6	34.9	36.0	37.2
Vehicles	2.3	8.5	16.5	27.5	40.0	60.8	95.6	173.0	273.6	372.7	431.7	484.7	542.1	582.1	614.2	636.0	650.6	673.2
Total	2.3	9.0	17.8	29.6	42.6	64.1	99.6	177.3	278.7	379.9	443.3	502.1	566.6	612.5	647.7	670.9	686.6	710.3
Market Transformation Benefits																		
High																		
Next Gen Trucks	0.4	0.7	1.9	3.1	4.5	8.4	25.1	45.4	65.4	88.1	107.3	143.9	180	211	231.9	231.9	230.4	230.4
Perceived Vehicle Price Reductions	0	0.2	0.4	0.8	1.4	2.1	3.2	5.3	7.9	11	13	15.5	17.4	19.1	21	22.8	24.7	26
Vehicle Cost Reduction	43	53.3	52.3	55.6	65.5	83.3	114	184.8	277	366.7	422.5	474.8	532.8	574.1	615	653.1	673.6	699
Total	43.4	54.2	54.6	59.5	71.4	93.8	142.3	235.5	350.3	465.8	542.8	634.2	730.2	804.2	867.9	907.8	928.7	955.4
Low																		
Next Gen Trucks	0.4	0.7	1.9	3.1	4.5	8.4	25.1	45.4	65.4	88.1	107.3	143.9	180	211	231.9	231.9	230.4	230.4

Benefit Category	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Perceived Vehicle Price Reductions	0	0.2	0.4	0.8	1.4	2.1	3.2	5.3	7.9	11	13	15.5	17.4	19.1	21	22.8	24.7	26
Vehicle Cost Reduction	43	53.3	52.3	55.6	65.5	83.3	114	184.8	277	366.7	422.5	474.8	532.8	574.1	615	653.1	673.6	699
Total	43.4	54.2	54.6	59.5	71.4	93.8	142.3	235.5	350.3	465.8	542.8	634.2	730.2	804.2	867.9	907.8	928.7	955.4

Source: NREL

Table 44: Summary of PM2.5 Reductions (Metric Tons per Year) for All Benefit Categories

Benefit Category	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Expected Benefits																		
Fuel Production	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fueling Infrastructure	0.0	0.0	0.1	0.1	0.2	0.3	0.4	0.4	0.5	0.8	1.3	2.1	3.0	3.1	2.5	1.6	1.7	1.7
Vehicles	0.0	0.0	0.1	0.1	0.2	0.6	2.3	5.7	9.5	11.9	13.9	15.9	17.8	19.6	21.4	23.2	24.8	26.5
Total	0.0	0.1	0.1	0.3	0.4	0.9	2.7	6.1	10.0	12.7	15.2	18.0	20.8	22.7	23.9	24.8	26.5	28.3
Market Transformation Benefits																		
High																		
Next Gen Trucks	0	0	0.4	0.7	1.1	2	3.7	5.5	7.3	9.7	13.2	17.4	21.5	24.6	25.4	25.4	25.3	25.3
Perceived Vehicle Price Reductions	0	0	0.1	0.1	0.2	0.4	0.6	1.1	1.4	1.7	1.9	2.2	2.4	2.7	2.9	3	3.2	3.3
Vehicle Cost Reduction	7.9	9.8	9.7	9.5	9.5	9.6	11.2	14.9	19.1	21.5	23.5	25.4	27.2	29.2	30.7	32.1	33.5	34.7
Total	7.9	9.8	10.2	10.3	10.8	12	15.5	21.5	27.8	32.9	38.6	45	51.1	56.5	59	60.5	62	63.3
Low																		
Next Gen Trucks	0	0	0	0	0	0.1	0.2	0.3	0.5	0.6	0.8	1	1.3	1.5	1.7	1.7	1.7	1.7

Benefit Category	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Perceived Vehicle Price Reductions	0	0	0	0.1	0.1	0.2	0.3	0.5	0.7	0.8	0.9	0.9	1	1.1	1.1	1.2	1.2	1.3
Vehicle Cost Reduction	5	6.1	5.9	5.7	5.7	5.8	7.4	10.7	14.5	16.6	18.4	20.2	21.9	23.7	25.3	26.9	28.4	30
Total	5	6.1	5.9	5.8	5.8	6.1	7.9	11.5	15.7	18	20.1	22.1	24.2	26.3	28.1	29.8	31.3	33

Source: NREL

Recommendations to Improve Benefit Estimation Methods

Although the current CTP project benefit estimates include many improvements to the method in the 2014 Benefits Report, additional enhancements to the input data and calculation method could provide additional realism and accuracy. For the two categories of benefits, the following improvements should be considered for future benefit analyses.

Expected Benefit Estimation Methodology

- Increase accuracy of input data including percentage of manufacturing capacity being used, and time-dependent energy efficiency ratio factors.
- Improve the geographic distribution of the benefits using vehicle drive patterns.
- Spatially disaggregate (break down) the electricity carbon intensity by region based on PLEXOS data.

Market Transformation Benefit Estimation Methodology

- Explicitly model competitive dynamics between advanced and incumbent technologies.
- Update the medium- and heavy-duty manufacturing benefits modeling method based on the latest research.
- Adopt the latest market transformation benefits analysis modeling being done in the alternative vehicle refueling infrastructure research.

GLOSSARY

ALTERNATIVE AND RENEWABLE FUELS AND VEHICLE TECHNOLOGY PROGRAM (ARFVTP) — Now known as the Clean Transportation Program, created by Assembly Bill 118 (Núñez, Chapter 750, Statutes of 2007), with an annual budget of about $100 million. Supports projects that develop and improve alternative and renewable low-carbon fuels, improve alternative and renewable fuels for existing and developing engine technologies, and expand transit and transportation infrastructures. Also establishes workforce training programs, conducts public education and promotion, and creates technology centers, among other tasks.

BATTERY-ELECTRIC VEHICLE (BEV) — Also known as an "all-electric" vehicle (AEV), 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 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 (CO2) — A colorless, odorless, nonpoisonous gas that is a normal part of the air. Carbon dioxide is exhaled by humans and animals and is absorbed by green growing things and the sea. CO2 is the greenhouse gas whose concentration is being most affected directly by human activities. CO2 also serves as the reference to compare all other greenhouse gases (see carbon dioxide equivalent).

CARBON DIOXIDE EQUIVALENT (CO2e) — 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.

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.[31]

DIESEL GALLON EQUIVALENT (DGE) — The amount of alternative fuel it takes to equal the energy content of one gallon of diesel fuel.

ELECTRIC VEHICLE MILES TRAVELED (eVMT) — Refers to miles driven using electric power over a given period. The more general term, VMT, is a measure of overall miles driven over a period.

ELECTRIC VEHICLE SUPPLY EQUIPMENT (EVSE) — Infrastructure designed to supply power to EVs. EVSE can charge a wide variety of EVs, including BEVs and PHEVs.

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 (CO_2), methane (CH_4), nitrous oxide (NOx), halogenated fluorocarbons (HCFCs), ozone (O^3), per fluorinated carbons (PFCs), and hydrofluorocarbons (HFCs).

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.

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.

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[31] About the Clean Vehicle Rebate Program https://cleanvehiclerebate.org/eng/about-cvrp.

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.[32]

NATURAL GAS (NG) — Hydrocarbon gas found in the earth, composed of methane, ethane, butane, propane, and other gases.

NITROGEN OXIDES (OXIDES OF NITROGEN, NOx) — A general term pertaining to compounds of nitric oxide (NO), nitrogen dioxide (NO_2), and other oxides of nitrogen. Nitrogen oxides are typically created during combustion and are major contributors to smog formation and acid deposition. NO_2 is a criteria air pollutant and may result in numerous adverse health effects.

PARTICULATE MATTER (PM) — 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) — PHEVs are 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 (similar to a conventional hybrid).

WILLINGNESS TO PAY (WTP) – WTP is the amount of value that is derived from the investment in Plugin Electric Vehicle charging infrastructure.

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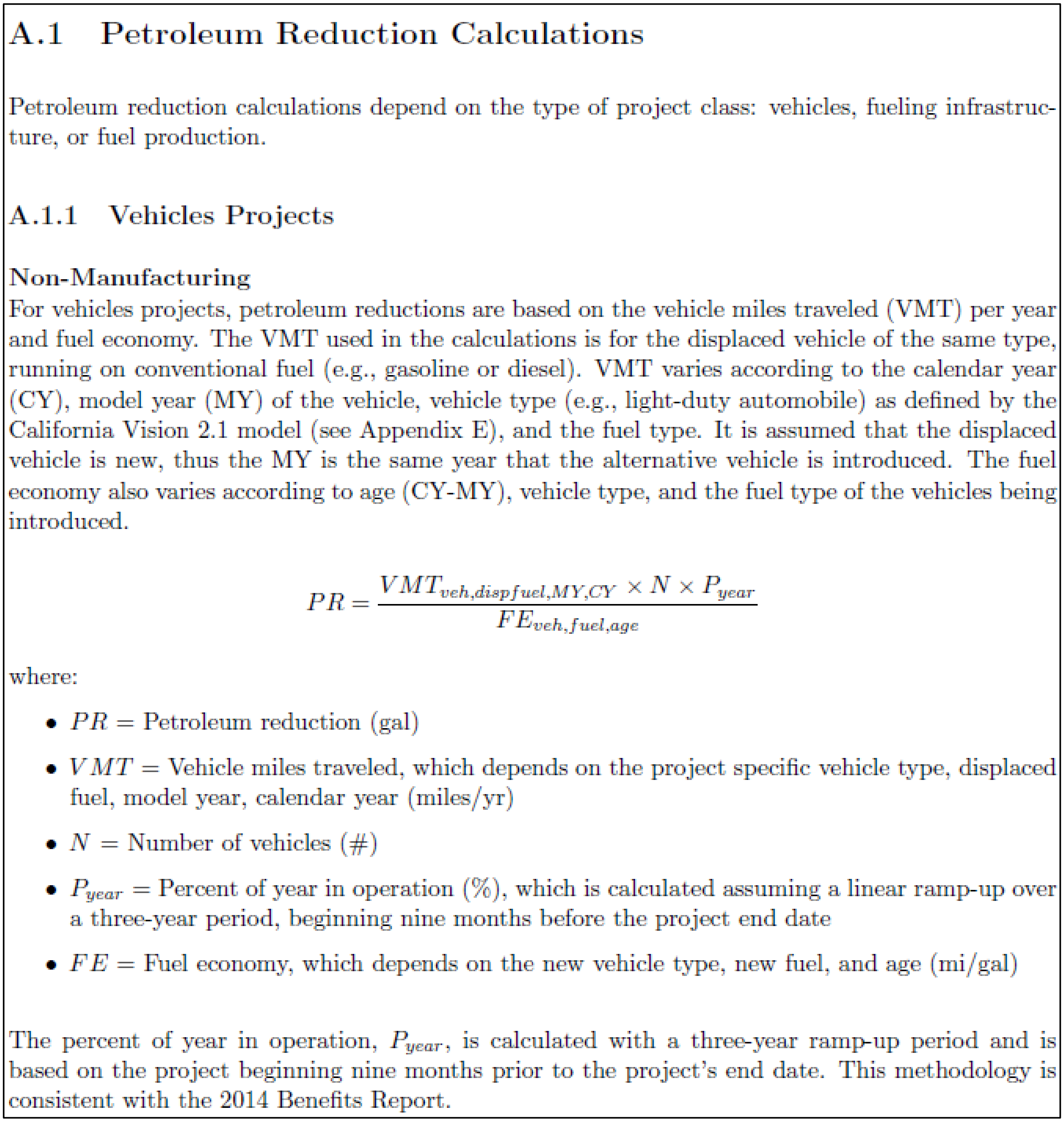
[32] About NREL https://www.nrel.gov/about/

APPENDIX A:
Detailed Calculation Methodology Summary

Figure A-1 provides a summary of the methodology used in this report.

Figure A-1: Methodology Summary



A.1 Petroleum Reduction Calculations

Petroleum reduction calculations depend on the type of project class: vehicles, fueling infrastructure, or fuel production.

A.1.1 Vehicles Projects

Non-Manufacturing

For vehicles projects, petroleum reductions are based on the vehicle miles traveled (VMT) per year and fuel economy. The VMT used in the calculations is for the displaced vehicle of the same type, running on conventional fuel (e.g., gasoline or diesel). VMT varies according to the calendar year (CY), model year (MY) of the vehicle, vehicle type (e.g., light-duty automobile) as defined by the California Vision 2.1 model (see Appendix E), and the fuel type. It is assumed that the displaced vehicle is new, thus the MY is the same year that the alternative vehicle is introduced. The fuel economy also varies according to age (CY-MY), vehicle type, and the fuel type of the vehicles being introduced.

$$PR = \frac{VMT_{veh,dispfuel,MY,CY} \times N \times P_{year}}{FE_{veh,fuel,age}}$$

where:

- PR = Petroleum reduction (gal)
- VMT = Vehicle miles traveled, which depends on the project specific vehicle type, displaced fuel, model year, calendar year (miles/yr)
- N = Number of vehicles (#)
- P_{year} = Percent of year in operation (%), which is calculated assuming a linear ramp-up over a three-year period, beginning nine months before the project end date
- FE = Fuel economy, which depends on the new vehicle type, new fuel, and age (mi/gal)

The percent of year in operation, P_{year}, is calculated with a three-year ramp-up period and is based on the project beginning nine months prior to the project's end date. This methodology is consistent with the 2014 Benefits Report.

Manufacturing

As with the non-manufacturing vehicles projects, it is assumed that the new vehicles displace new conventional vehicles. For manufacturing projects, vehicle stock is tracked over time and new conventional fuel vehicles are continually displaced each year by the new alternative vehicles that were manufactured in that year. The VMT and fuel economy used in the petroleum reduction calculations are based on the model year corresponding to the year of manufacture. Thus, the petroleum reductions for one year from one vehicles manufacturing project can be based on various model years of the vehicle.

The medium- and heavy-duty truck manufacturing projects using T6 Instate Small or T7 Other Port vehicle types were constrained to produce only a set number of vehicles matching the Energy Commission's Transportation Energy Forecast for 2020 and 2025, as shown in the table below.

Table 1: Annual Cap on T6 Instate Small and T7 Other Port Vehicles Manufacturing

Year	**Annual Cap** (number of vehicles)
2011	375
2012	750
2013	1125
2014	1500
2015	1875
2016	2250
2017	2625
2018	3000
2019	3375
2020	3750
2021	4500
2022	5250
2023	6000
2024	6750
2025	7500

In addition, the benefits for all vehicle manufacturing projects were constrained to only account for up to 5,000 cumulative vehicles per project. Thus, if a T6 Instate Small or T7 Other Port project began in 2023, we would only account for 5,000 vehicles being manufactured in that year and none in the years following.

The petroleum reductions for vehicles manufacturing projects are calculated using the same formula as non-manufacturing projects, with the only differences being that model year varies and the number of vehicles by model year (and cumulative total) is capped as described above.

A.1.2 Fueling Infrastructure Projects

EVSE Infrastructure

Petroleum reductions are based on e_{miles} which are determined by the charger type and EVI Pro model estimation of e_{miles} per charger, by type:

$$e_{miles} = 3{,}383 \times L1_{com} + 159{,}487 \times L2_{com} + 11{,}093 \times L2_{res} + 67{,}690 \times DC$$

where:

- e_{miles} = Electric vehicle-miles supported due to project investment (# of miles)
- $L1_{com}$ = Number of level 1 commercial charge points (# charge points)
- $L2_{com}$ = Number of level 2 commercial charge points (# charge points)
- $L2_{res}$ = Number of level 2 residential charge points (# charge points)
- DC = Number of DC fast charge points (# charge points)

EVSE petroleum reductions are calculated as:

$$PR = \frac{e_{miles} \times P_{year}}{FE_{veh,fuel,age}}$$

where:

- PR = Petroleum reductions (gal)
- e_{miles} = Electric vehicle-miles supported due to project investment (# of miles) [calculated as shown above]
- P_{year} = Percent of year in operation (%), which is calculated assuming a linear ramp-up over a three-year period, beginning nine months before the project end date
- FE = Fuel economy, which depends on the new vehicle type, new fuel, and age (mi/gal)

Hydrogen

Non-EVSE infrastructure petroleum reductions are based on the fuel production throughput, energy efficiency ratio, and percent of year operating. For hydrogen infrastructure, the EER is based on the ratio of the new FCEV fuel economy and a new conventional vehicle fuel economy in the year analyzed. All other fuel types (i.e., ethanol, natural gas, and biodiesel) are calculated using a constant EER of 1 according to the relative EERs used in the 2017 CARB LCFS Price Calculator. For biodiesel, the fuel production throughput FP must undergo a unit conversion from *dge* to *gge* using a ratio of:

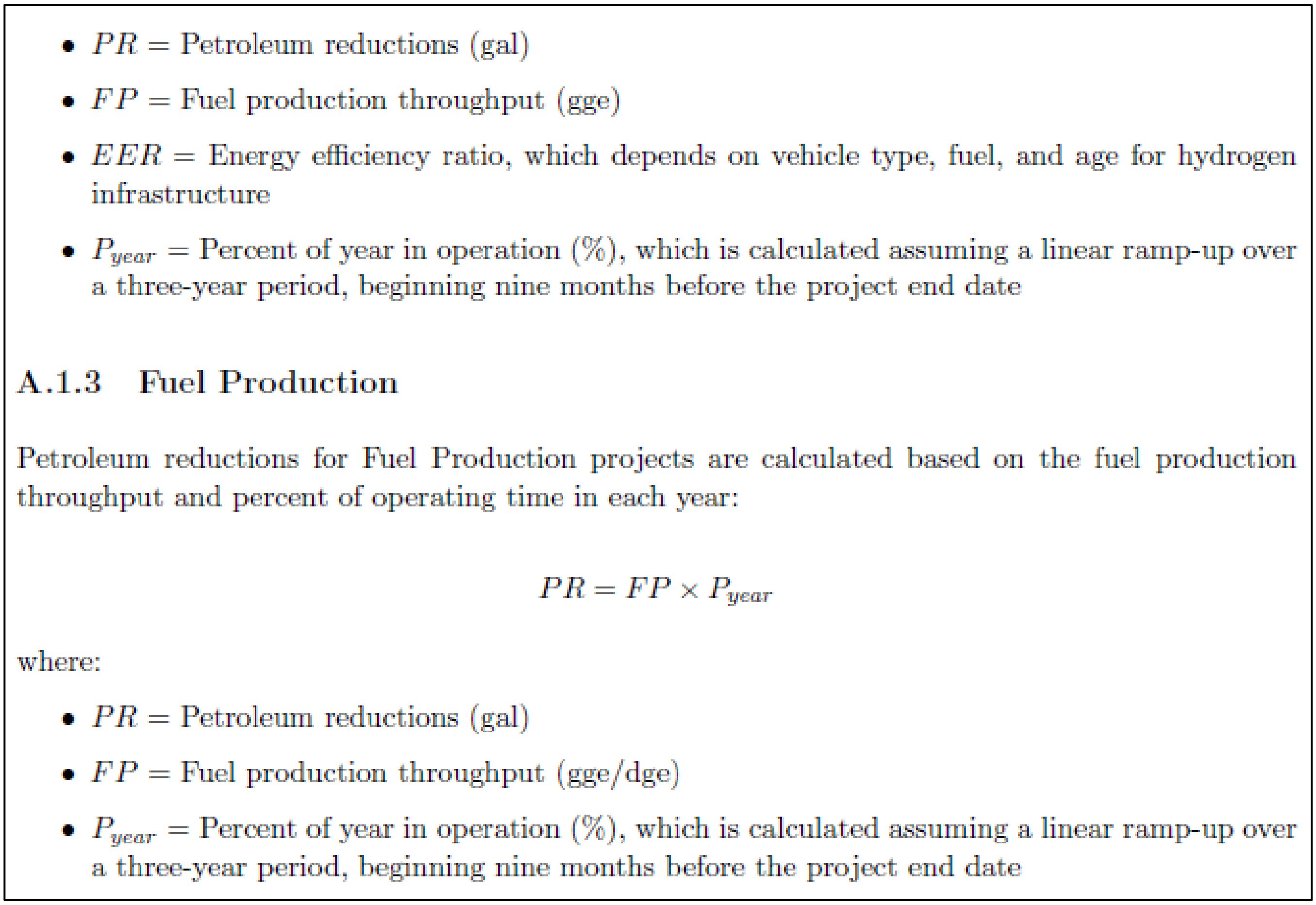
$$\frac{125{,}000 \text{ BTU per gallon gasoline}}{139{,}000 \text{ BTU per gallon diesel}}$$

.

Once the fuel production throughput FP for all non-EVSE infrastructure projects is in *gge*, petroleum reductions are calculated as:

$$PR = EER_{veh,fuel,age} \times FP \times P_{year}$$

where:



- PR = Petroleum reductions (gal)
- FP = Fuel production throughput (gge)
- EER = Energy efficiency ratio, which depends on vehicle type, fuel, and age for hydrogen infrastructure
- P_{year} = Percent of year in operation (%), which is calculated assuming a linear ramp-up over a three-year period, beginning nine months before the project end date

A.1.3 Fuel Production

Petroleum reductions for Fuel Production projects are calculated based on the fuel production throughput and percent of operating time in each year:

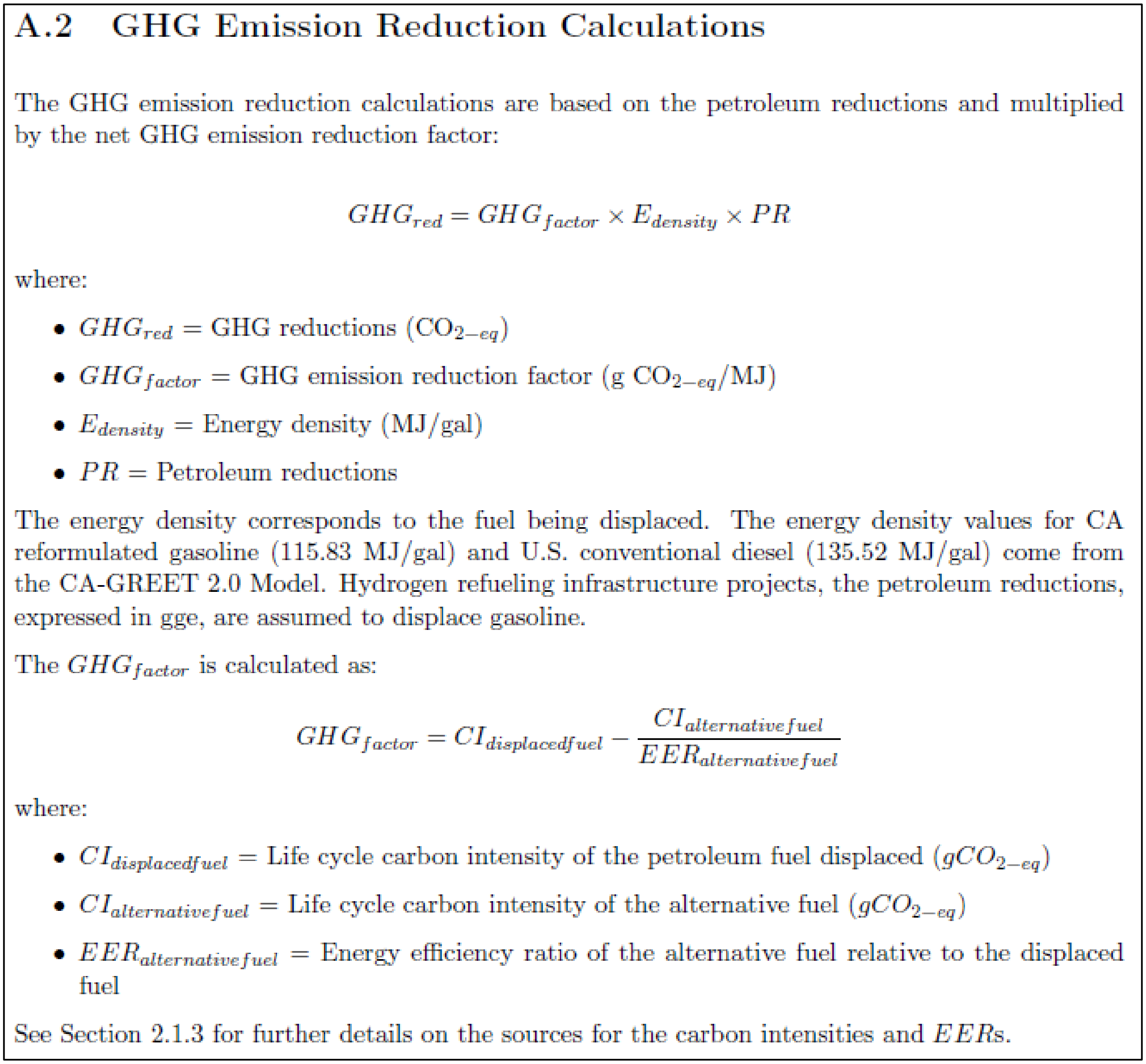
$$PR = FP \times P_{year}$$

where:

- PR = Petroleum reductions (gal)
- FP = Fuel production throughput (gge/dge)
- P_{year} = Percent of year in operation (%), which is calculated assuming a linear ramp-up over a three-year period, beginning nine months before the project end date

Source: NREL

Figure A-2: GHG Emission Reductions



A.2 GHG Emission Reduction Calculations

The GHG emission reduction calculations are based on the petroleum reductions and multiplied by the net GHG emission reduction factor:

$$GHG_{red} = GHG_{factor} \times E_{density} \times PR$$

where:

- GHG_{red} = GHG reductions (CO_{2-eq})
- GHG_{factor} = GHG emission reduction factor (g CO_{2-eq}/MJ)
- $E_{density}$ = Energy density (MJ/gal)
- PR = Petroleum reductions

The energy density corresponds to the fuel being displaced. The energy density values for CA reformulated gasoline (115.83 MJ/gal) and U.S. conventional diesel (135.52 MJ/gal) come from the CA-GREET 2.0 Model. Hydrogen refueling infrastructure projects, the petroleum reductions, expressed in gge, are assumed to displace gasoline.

The GHG_{factor} is calculated as:

$$GHG_{factor} = CI_{displacedfuel} - \frac{CI_{alternativefuel}}{EER_{alternativefuel}}$$

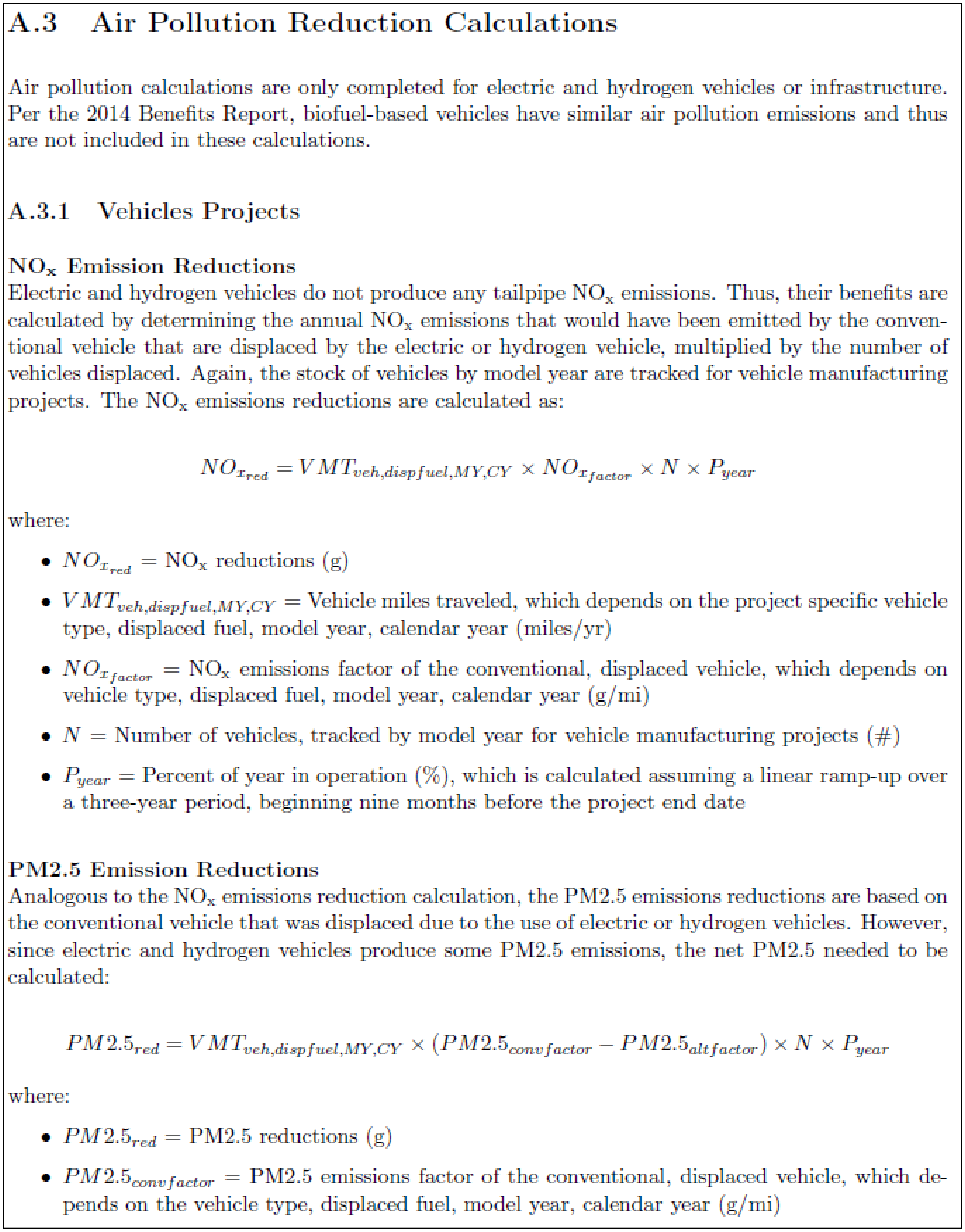
where:

- $CI_{displacedfuel}$ = Life cycle carbon intensity of the petroleum fuel displaced (gCO_{2-eq})
- $CI_{alternativefuel}$ = Life cycle carbon intensity of the alternative fuel (gCO_{2-eq})
- $EER_{alternativefuel}$ = Energy efficiency ratio of the alternative fuel relative to the displaced fuel

See Section 2.1.3 for further details on the sources for the carbon intensities and EERs.

Source: NREL

Figure A-3: Air Pollution Reduction



A.3 Air Pollution Reduction Calculations

Air pollution calculations are only completed for electric and hydrogen vehicles or infrastructure. Per the 2014 Benefits Report, biofuel-based vehicles have similar air pollution emissions and thus are not included in these calculations.

A.3.1 Vehicles Projects

NO_x Emission Reductions

Electric and hydrogen vehicles do not produce any tailpipe NO_x emissions. Thus, their benefits are calculated by determining the annual NO_x emissions that would have been emitted by the conventional vehicle that are displaced by the electric or hydrogen vehicle, multiplied by the number of vehicles displaced. Again, the stock of vehicles by model year are tracked for vehicle manufacturing projects. The NO_x emissions reductions are calculated as:

$$NO_{x_{red}} = VMT_{veh,dispfuel,MY,CY} \times NO_{x_{factor}} \times N \times P_{year}$$

where:

- $NO_{x_{red}}$ = NO_x reductions (g)
- $VMT_{veh,dispfuel,MY,CY}$ = Vehicle miles traveled, which depends on the project specific vehicle type, displaced fuel, model year, calendar year (miles/yr)
- $NO_{x_{factor}}$ = NO_x emissions factor of the conventional, displaced vehicle, which depends on vehicle type, displaced fuel, model year, calendar year (g/mi)
- N = Number of vehicles, tracked by model year for vehicle manufacturing projects (#)
- P_{year} = Percent of year in operation (%), which is calculated assuming a linear ramp-up over a three-year period, beginning nine months before the project end date

PM2.5 Emission Reductions

Analogous to the NO_x emissions reduction calculation, the PM2.5 emissions reductions are based on the conventional vehicle that was displaced due to the use of electric or hydrogen vehicles. However, since electric and hydrogen vehicles produce some PM2.5 emissions, the net PM2.5 needed to be calculated:

$$PM2.5_{red} = VMT_{veh,dispfuel,MY,CY} \times (PM2.5_{convfactor} - PM2.5_{altfactor}) \times N \times P_{year}$$

where:

- $PM2.5_{red}$ = PM2.5 reductions (g)
- $PM2.5_{convfactor}$ = PM2.5 emissions factor of the conventional, displaced vehicle, which depends on the vehicle type, displaced fuel, model year, calendar year (g/mi)

- $PM2.5_{altfactor}$ = PM2.5 emissions factor of the alternative vehicle, which depends on vehicle type, fuel, model year, calendar year (g/mi)
- N = Number of vehicles, tracked by model year for vehicle manufacturing projects (#)
- P_{year} = Percent of year in operation (%), which is calculated assuming a linear ramp-up over a three-year period, beginning nine months before the project end date

A.3.2 Fueling Infrastructure

Electric and hydrogen fueling infrastructure benefits are determined by estimating how many conventional vehicle miles are displaced due to the infrastructure. These vehicle-miles are then multiplied by the NO_x emission factor of the displaced conventional vehicle the percent of year in operation.

EVSE

The displaced vehicle-miles are equivalent to the e_{miles} calculated in the petroleum reduction calculation. The NO_x emissions reductions are calculated as:

$$NO_{x_{red}} = e_{miles} \times NO_{x_{factor}} \times P_{year}$$

where:

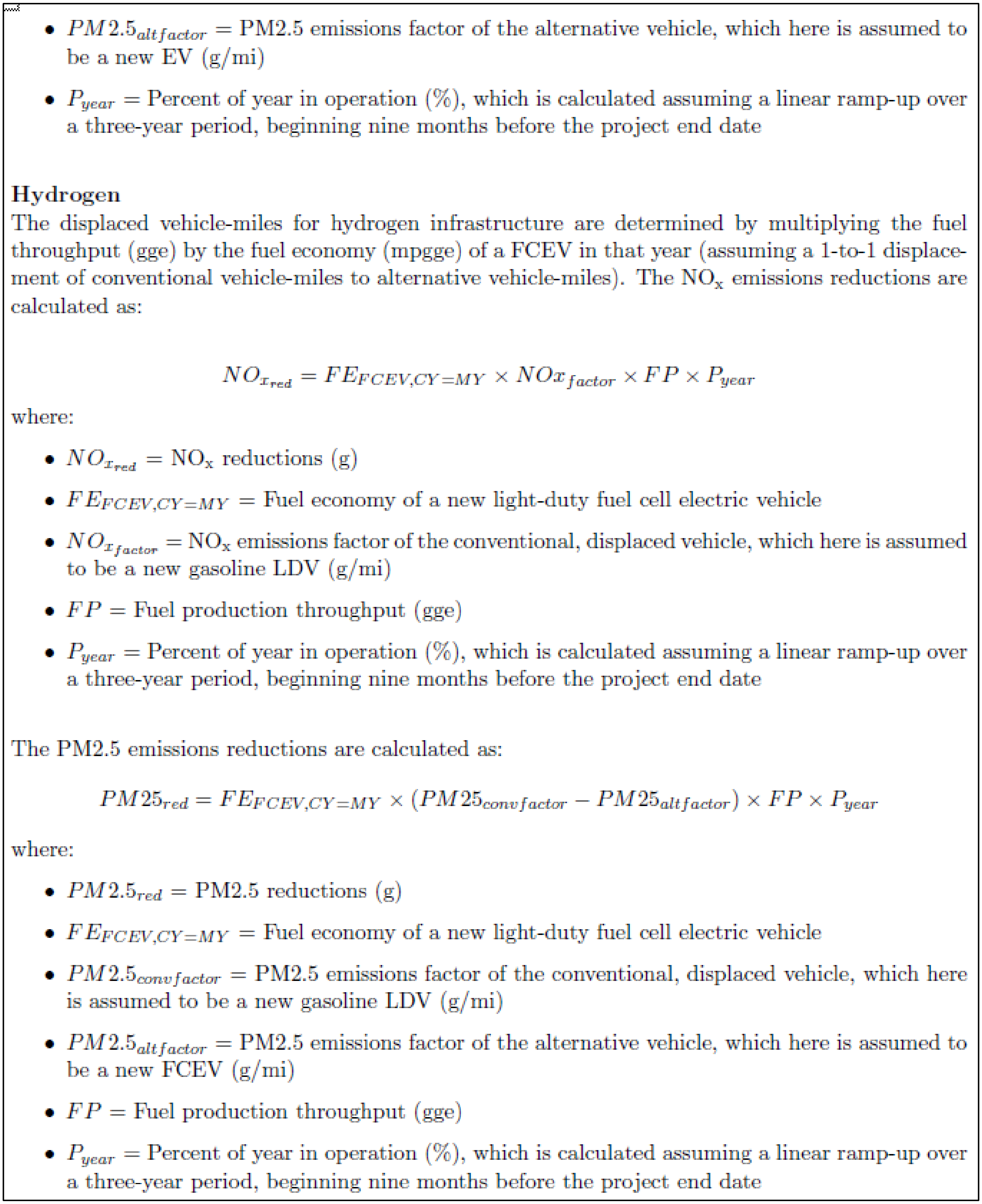
- $NO_{x_{red}}$ = NO_x reductions (g)
- e_{miles} = Electric vehicle-miles supported due to project investment (# of miles)
- $NO_{x_{factor}}$ = NO_x emissions factor of the conventional, displaced vehicle, which here is assumed to be a new gasoline LDV (g/mi)
- P_{year} = Percent of year in operation (%), which is calculated assuming a linear ramp-up over a three-year period, beginning nine months before the project end date

The PM2.5 calculations are similar, only they account for the emissions produced by the new alternative vehicle:

$$PM25_{red} = e_{miles} \times (PM25_{convfactor} - PM25_{altfactor}) \times P_{year}$$

where:

- $PM2.5_{red}$ = PM2.5 reductions (g)
- e_{miles} = Electric vehicle-miles supported due to project investment (# of miles)
- $PM2.5_{convfactor}$ = PM2.5 emissions factor of the conventional, displaced vehicle, which here is assumed to be a new gasoline LDV (g/mi)



- $PM2.5_{altfactor}$ = PM2.5 emissions factor of the alternative vehicle, which here is assumed to be a new EV (g/mi)
- P_{year} = Percent of year in operation (%), which is calculated assuming a linear ramp-up over a three-year period, beginning nine months before the project end date

Hydrogen

The displaced vehicle-miles for hydrogen infrastructure are determined by multiplying the fuel throughput (gge) by the fuel economy (mpgge) of a FCEV in that year (assuming a 1-to-1 displacement of conventional vehicle-miles to alternative vehicle-miles). The NO_x emissions reductions are calculated as:

$$NO_{x_{red}} = FE_{FCEV,CY=MY} \times NOx_{factor} \times FP \times P_{year}$$

where:

- $NO_{x_{red}}$ = NO_x reductions (g)
- $FE_{FCEV,CY=MY}$ = Fuel economy of a new light-duty fuel cell electric vehicle
- $NO_{x_{factor}}$ = NO_x emissions factor of the conventional, displaced vehicle, which here is assumed to be a new gasoline LDV (g/mi)
- FP = Fuel production throughput (gge)
- P_{year} = Percent of year in operation (%), which is calculated assuming a linear ramp-up over a three-year period, beginning nine months before the project end date

The PM2.5 emissions reductions are calculated as:

$$PM25_{red} = FE_{FCEV,CY=MY} \times (PM25_{convfactor} - PM25_{altfactor}) \times FP \times P_{year}$$

where:

- $PM2.5_{red}$ = PM2.5 reductions (g)
- $FE_{FCEV,CY=MY}$ = Fuel economy of a new light-duty fuel cell electric vehicle
- $PM2.5_{convfactor}$ = PM2.5 emissions factor of the conventional, displaced vehicle, which here is assumed to be a new gasoline LDV (g/mi)
- $PM2.5_{altfactor}$ = PM2.5 emissions factor of the alternative vehicle, which here is assumed to be a new FCEV (g/mi)
- FP = Fuel production throughput (gge)
- P_{year} = Percent of year in operation (%), which is calculated assuming a linear ramp-up over a three-year period, beginning nine months before the project end date

Source: NREL

APPENDIX B:
Python Analysis Framework

The expected benefits (petroleum reduction, GHG emissions, NOx and PM2.5) model was converted from an Excel-based model (2014 ARFVTP Benefits Report) to a chain model in python. The Excel model was converted to python to improve reproducibility, consistency, transparency, and integrity. The code is documented and stored on GitHub for reproducibility and potential back-up as needed for the project. The various input data from the Energy Commission staff, the Energy Commission's Transportation Energy Forecast, life-cycle assessment models (CA-GREET) [8], and vehicle stock models (CA-VISION) [9] are stored in tables in the database.

Starting with the input tables, the model executes a series of sequential data manipulations to complete the calculations as described in this report. The framework can be broken into four separate sections. The first section joins the projects data table to the feedstock and energy density tables and renames column titles when appropriate. Basic raw data post processing and low-level calculations are also performed in this section. The resulting output is a master view of all projects data with additional calculated columns necessary for later parts of the framework. By performing the majority of the simple data transformations at the earliest portion of the model, data changes trickle down through the rest of the framework, ensuring model integrity and eliminating redundancy in the code.

The second section of the query chain joins the resulting view from section one with the dates table to associate each project with a timeline ranging from 2010 to 2050. The view then calculates the percent year operation for each project by year. The percent year operation was used in the Excel-based model, and the methodology for calculating the percent year operation was maintained to account for an assumed 3-year ramp-up period for all projects. This 3-year ramp-up period is expected to begin 9 months before the scheduled project end date and linearly increases until 100 percent operation is achieved. For each year during the ramp-up period, the SQL calculations average the start and end percentage of operation, weighted by the number of days during the year that ramp-up is occurring.

The third section of the model breaks out the data into separate views for each major project class and performs final data transformations to ensure that the information is ready for the benefits calculations. The vehicles projects are further broken out to represent manufacturing vehicles and non-manufacturing vehicles. Project classes used in the air pollutions calculations are then joined to the vehicle stock model data to retrieve information on fuel economy, VMT, PM2.5 values, and NOx values for new and replaced vehicle types.

To account for aging manufactured vehicles and their impacts on the expected benefits over time, further SQL manipulation of the data was necessary for the vehicles manufacturing projects in this section of the query chain. This included transforming the data into a cascading dates structure that tracks vehicles by model year for each year that passed. Additional constraints were also placed on this view to ensure that the resulting benefits better matched the CEC medium duty/heavy duty Transportation Energy Forecast. Based on the 2020 and 2025 forecasts, a table defining the caps by year for both the total vehicles sold per year for all qualifying projects and the total number of vehicles sold per project (5,000 cumulative vehicles per project) for all years was uploaded to the database. Minimal post processing of this information was performed to account for the number of qualifying projects where the cap will apply for the total vehicles sold per year. These final caps were then applied to all manufacturing projects with medium duty or heavy-duty trucks.

The fourth section of the query chain performs final benefits calculations for petroleum reductions, GHG reductions, and air pollution (NOx and PM2.5) Reductions. Calculations for each type of benefits vary depending on project class/subclass. Views from the third section of the query chain are utilized for each calculation when appropriate and then unioned together to achieve the final combined view for each type of benefits. Calculations using the vehicles manufacturing view must account for the cascading dates structure that breaks out the data by vehicle model year for each year that passes. Manufacturing calculations are therefore performed by vehicle model year and the results are summed over the year and project ID to achieve the desired data structure for the final views.

APPENDIX C:
California ARB Vision 2.1 Vehicle Types

The table below describes the passenger vehicle and heavy-duty vehicle types included in the CARB Vision 2.1 modules.

Table D-1: CA-Vision Vehicle Categories

EMFAC Vehicle ID	Vision Model	Description
LDA	PVM	Light-Duty Automobiles (i.e. Passenger Cars)
LDT1	PVM	Light-Duty Trucks (0-3,750 lbs GVWR)
LDT2	PVM	Light-Duty Trucks (3,751-5,750 lbs GVWR)
MDV	PVM	Medium-Duty Trucks (5,751-8,500 lbs GVWR)
UBUS	PVM	Urban Buses
SBUS	PVM	School Buses
OBUS	PVM	Other Buses
LHD1	HDV	Light-Heavy-Duty Trucks (GVWR 8501-10000 lbs)
LHD2	HDV	Light-Heavy-Duty Trucks (GVWR 10001-14000 lbs)
T6 Ag	HDV	Medium-Heavy Duty Diesel Agriculture Truck
T6 CAIRP heavy	HDV	Medium-Heavy Duty Diesel CA International Registration Plan Truck with GVWR>26000 lbs
T6 CAIRP small	HDV	Medium-Heavy Duty Diesel CA International Registration Plan Truck with GVWR<=26000 lbs
T6 instate construction heavy	HDV	Medium-Heavy Duty Diesel instate construction Truck with GVWR>26000 lbs
T6 instate construction small	HDV	Medium-Heavy Duty Diesel instate construction Truck with GVWR<=26000 lbs
T6 instate heavy	HDV	Medium-Heavy Duty Diesel instate Truck with GVWR>26000 lbs
T6 instate small	HDV	Medium-Heavy Duty Diesel instate Truck with GVWR<=26000 lbs
T6 OOS heavy	HDV	Medium-Heavy Duty Diesel Out-of-state Truck with GVWR>26000 lbs
T6 OOS small	HDV	Medium-Heavy Duty Diesel Out-of-state Truck with GVWR<=26000 lbs
T6 Public	HDV	Medium-Heavy Duty Diesel Public Fleet Truck
T6 utility	HDV	Medium-Heavy Duty Diesel Utility Fleet Truck
T6TS	HDV	Medium-Heavy Duty Gasoline Truck
T7 Ag	HDV	Heavy-Heavy Duty Diesel Agriculture Truck
T7 CAIRP	HDV	Heavy-Heavy Duty Diesel CA International Registration Plan Truck
T7 CAIRP construction	HDV	Heavy-Heavy Duty Diesel CA International Registration Plan Construction Truck
T7 NNOOS	HDV	Heavy-Heavy Duty Diesel Non-Neighboring Out-of-state Truck
T7 NOOS	HDV	Heavy-Heavy Duty Diesel Neighboring Out-of-state Truck
T7 other port	HDV	Heavy-Heavy Duty Diesel Drayage Truck at Other Facilities
T7 POAK	HDV	Heavy-Heavy Duty Diesel Drayage Truck in Bay Area
T7 POLA	HDV	Heavy-Heavy Duty Diesel Drayage Truck near South Coast
T7 Public	HDV	Heavy-Heavy Duty Diesel Public Fleet Truck
T7 Single	HDV	Heavy-Heavy Duty Diesel Single Unit Truck
T7 single construction	HDV	Heavy-Heavy Duty Diesel Single Unit Construction Truck
T7 SWCV	HDV	Heavy-Heavy Duty Solid Waste Collection Truck
T7 tractor	HDV	Heavy-Heavy Duty Diesel Tractor Truck
T7 tractor construction	HDV	Heavy-Heavy Duty Diesel Tractor Construction Truck
T7 utility	HDV	Heavy-Heavy Duty Diesel Utility Fleet Truck
T7IS	HDV	Heavy-Heavy Duty Gasoline Truck
PTO	HDV	Power Take Off

Source: NREL

APPENDIX D:
Project-Specified Carbon Intensities

Table E-1 describes the life-cycle carbon intensities specified in the project descriptions that were used for calculating GHG reductions. The GHG emission reduction factor in the table is calculated based on the difference between the carbon intensity of the replaced conventional fuel and the specified carbon intensity of the project scaled by the energy efficiency ratio.

Table E-1: Project-Specific Carbon Intensities Based on Project Description

Fuel	**Clean Transportation Program Agreement** **(Some Include Feedstock Type)**	**Life-Cycle Carbon Intensity** (g CO_2e/MJ)	**GHG Emission Reduction Factor** (g CO_2e/MJ)
Biodiesel	ARV-11-015 - UCO	11.76	88.24
	ARV-12-026 - Tallow and UCO	31.37	68.63
	ARV-11-016 - UCO	11.76	88.24
	ARV-10-024	-1.43	101.43
	ARV-10-022	11.76	88.24
	ARV-14-024 - Corn oil	4	96
	ARV-12-035 - UCO	11.76	88.24
	ARV-13-008 - Corn oil	59.11	40.89
	ARV-13-052 - UCO	4	96
	ARV-13-007 - UCO	14	86
	ARV-15-008	46	54
	ARV-15-011	55.25	44.75
	ARV-16-018 Flex-feed	13.93	86.07
	ARV-16-XXX New Leaf	15.14	84.86
	ARV-16-XXX Wonderful Renewable Energy	2.92	97.08
	ARV-16-XXX Crimson Biodiesel	31	69
	ARV-16-XXX Wonderful Renewable Biodiesel	13.32	86.68

Fuel	**Clean Transportation Program Agreement** **(Some Include Feedstock Type)**	**Life-Cycle Carbon Intensity** ($g\ CO_2e/MJ$)	**GHG Emission Reduction Factor** ($g\ CO_2e/MJ$)
Ethanol	ARV-11-018	23.6	72.9
	ARV-10-028	23.15	73.35
	ARV-14-021	65.02	31.48
	ARV-14-026	69.51	26.99
	ARV-14-027	70.25	26.25
	ARV-10-030	58.11	38.39
	ARV-10-031	56.82	39.68
	ARV-10-033	60.27	36.23
	ARV-15-009	26.9	69.6
	ARV-15-017	22.2	74.3
	ARV-16-XXX Sugar beets	7.18	89.32
Fischer and Tropsch Diesel	ARV-11-019 - Municipal solid waste	33	67
Natural Gas	ARV-10-016	15.2	84.8
	ARV-10-026	-15.29	115.29
	ARV-12-021	-15.29	115.29
	ARV-10-023	14.4	85.6
	ARV-12-031 - Landfill gas	-15.29	115.29
	ARV-10-052 - Dairy waste	-15.29	115.29
	ARV-10-053 - Dairy waste	-13.6	113.6
	ARV-10-040 - Dairy waste	-13.6	113.6
	ARV-10-003	-15.29	115.29
	ARV-11-021 - Dairy waste	-13.6	113.6
	ARV-14-028 - Dairy waste	11.5	88.5
	ARV-14-037 - Wood waste	-48.2	148.2
	ARV-14-029 - Dairy waste	-13.6	113.6

Fuel	**Clean Transportation Program Agreement** **(Some Include Feedstock Type)**	**Life-Cycle Carbon Intensity** (g CO_2e/MJ)	**GHG Emission Reduction Factor** (g CO_2e/MJ)
	ARV-15-054	-4.6	104.6
	ARV-15-067	-2.4	102.4
	ARV-16-XXX CR&R Inc Biomethane	-22.93	122.93
	ARV-16-XXX Kern Dairy Biogas	-276.24	376.24
	ARV-16-XXX Municipal solid waste Biomethane	-30	130
	ARV-16-XXX AD Food Waste	-18.12	118.12
	ARV-16-XXX Waste-to-Fuels	30.5	69.5
Renewable Diesel	ARV-14-022 - Tallow	16.14	83.86
	ARV-10-047	33.46	66.54
	ARV-10-027 - Algae	-22	122
	ARV-10-043 - Dairy waste	33.46	66.54
	ARV-14-034	16.4	83.6

Source: NREL