Alternative and Renewable Fuel and Vehicle Technology Program

DRAFT PROJECT REPORT

PROGRAM BENEFITS GUIDANCE

Analysis of Benefits Associated With Projects and Technologies Supported by the Alternative and Renewable Fuel and Vehicle Technology Program

NATIONAL RENEWABLE ENERGY LABORATORY

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PREFACE

Assembly Bill 118 (Núñez, Chapter 750, Statutes of 2007) created the Alternative and Renewable Fuel and Vehicle Technology Program (ARFVT Program). The statute, subsequently amended by Assembly Bill 109 (Núñez, Chapter 313, Statutes of 2008), authorizes the California Energy Commission to develop and deploy alternative and renewable fuels and advanced transportation technologies to help attain the state's climate change policies. Assembly Bill 109 also requires the Energy Commission 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. Recently signed Assembly Bill 8 (Perea, Chapter 401, Statutes of 2013) extends the expiration date of the ARFVT Program to January 1, 2024. The Energy Commission 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 nonroad 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.

The Energy Commission has contracted with the National Renewable Energy Laboratory through Agreement 600-11-002, issued on September 13, 2012, to assist with analysis and implementation of specific ARFVT topics, including guidance on benefits associated with ARFVTP.

ABSTRACT

The Alternative and Renewable Fuel and Vehicle Technologies Program (ARFVTP) supports a wide range of alternative, low-carbon fuel and vehicle projects in California. This report focuses on two types of ARFVTP benefits. *Expected benefits* reflect successful deployment of vehicles and fuels supported through program projects. *Market transformation benefits* represent benefits resulting from project influences on future market conditions to accelerated technology adoption rates. Data collected directly from ARFVTP projects funded from 2009 to first quarter 2014 are used as inputs to the benefits analysis, where possible. Expected benefit estimation methods rely primarily upon project-level data and result in year single-point estimates within the 2011 to 2025 analysis period. Results suggest that the 178 projects evaluated for expected benefits, representing an investment of $351.3 million in ARFVTP funds, could result in a reduction in petroleum fuel use by 236 million gallons per year and greenhouse gases (GHGs) by 1.7 million metric tonnes carbon dioxide equivalent ($MMTCO_2e$) per year by 2025. Market transformation benefits are described as accruing in addition to expected benefits. They are inherently more uncertain and theoretical than expected benefits, and are therefore reported as high and low ranges, with results suggesting reductions of 1.1 $MMTCO_2e$ to 2.5 $MMTCO_2e$ per year in GHG reductions and 102 million to 330 million gallons per year in petroleum fuel reductions by 2025. Taking both benefit types into account, results suggest that ARFVTP projects have the potential to make substantial progress toward meeting California's long-term GHG and petroleum fuel use reduction goals. As additional project data become available and market success with alternative and renewable fuels and vehicles grows, the analytic framework relied upon to develop these estimates will become more rigorous and will have a greater capacity to inform future ARFVTP activities.

Keywords: California Energy Commission, Alternative and Renewable Fuel and Vehicle Technology Program, National Renewable Energy Laboratory, program benefits, alternative fuels, advanced vehicles, greenhouse gas emissions, criteria emissions, petroleum reduction

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EXECUTIVE SUMMARY

This draft report updates and expands upon the previous Benefits Reports developed by the California Energy Commission in 2011 and the National Renewable Energy Laboratory (NREL) in 2013, and focuses on a select number of benefits that can be quantified with a reasonable degree of certainty. The research team evaluated benefits based upon data made available from 207 projects supported through contracts totaling $426 million in funds from the Advanced and Renewable Fuel and Vehicle Technology Program (ARFVTP). This is a subset of the 274 projects funded with $488 million in ARFVTP funds, as of March 31, 2014, and includes additional projects that were approved by the Energy Commission since June 30, 2013. Earlier results from the 2013 Draft NREL Benefits analysis were presented in the Energy Commission's *2013 Integrated Energy Policy Report* in November 2013. Benefit estimates are based upon the expected performance of each project, such as fuel used by vehicles or biofuels supplied by production facilities, as well as potential influences on future market adoption rates. Though additional ARFVTP activities exist and contribute to market growth, such as raising consumer awareness and enhancing policy development, the benefits from these activities are difficult to estimate quantitatively. The benefits estimated here are therefore subsets of the total benefits associated with ARFVTP activities. As additional data are collected from new and ongoing ARFVTP projects, the corresponding benefits can be evaluated consistently using the analytic framework described in this report. Quantifiable benefits, primarily reductions in greenhouse gas emissions and petroleum fuel use, fall into four categories:

- **Baseline Benefits:** expected to accrue without support from ARFVTP.
- **Expected Benefits:** directly associated with vehicles and fuels deployed through projects receiving ARFVTP funds. Project categories include vehicles, refueling infrastructure, and fuel production.
- **Market Transformation Benefits:** accrue due to the influence of ARFVTP projects on future market conditions to accelerate the adoption of new technologies. Influences include increased availability of public electric vehicle supply equipment and hydrogen refueling stations, consumer incentives for zero-emission vehicles (ZEVs), investments in zero-emission vehicle demonstrations and manufacturing facilities, and deployment of next-generation fuel production facilities and advanced truck demonstrations.
- **Required Carbon Market Growth Benefits:** associated with projections of future market growth trends comparable to those needed to achieve deep reductions in GHGs by 2050.

These benefit categories represent different states of knowledge about technological progress and market potential and draw upon data from different sources with different levels of detail and certainty. In general, the four categories proceed from a relatively high level of certainty about past trends and ongoing or near-term projects (baseline and expected benefits) to a high level of uncertainty about technology innovation, consumer behavior, and market dynamics (market transformation and market growth benefits). Baseline benefits are not estimated in this report; the category serves as a conceptual guide to differentiate ARFVTP influences from other influences or market trends. Required carbon market growth benefits, referred to simply as *market growth benefits*, are a relatively simple representation of GHG reduction trends required to stay on track to meet California's long-term GHG reduction goals. The large majority of the benefits analysis therefore focuses on expected and market transformation benefits. The methodologies and results for expected, market transformation, and market growth benefits are discussed in separate chapters of the report, followed by a brief summary and suggestions for future enhancements to the estimation method.

Expected benefits are quantified as the most likely benefits to occur from ARFVTP projects being executed successfully, assuming one-to-one substitution of the service or technical performance of the new technology replacing the incumbent technology. In contrast, market transformation benefits are an estimate of a range of high and low influences on future market adoption rates, reflecting the uncertainty of future projections. Table ES-1 summarizes the GHG and petroleum fuel reductions associated with expected, market transformation, and market growth benefits. For expected benefits, total annual GHG reductions by 2025 are estimated at 1.7 million tonnes carbon dioxide equivalent ($MMTCO_2e$) per year, and petroleum fuel reductions are estimated at 236 million gallons per year. Market transformation benefits range from 1.1 to 2.5 $MMTCO_2e$ per year in GHG reductions and 102 million to 330 million gallons per year in petroleum fuel reductions by 2025.

Table ES-1: Summary of GHG and Petroleum Fuel Reduction Benefits

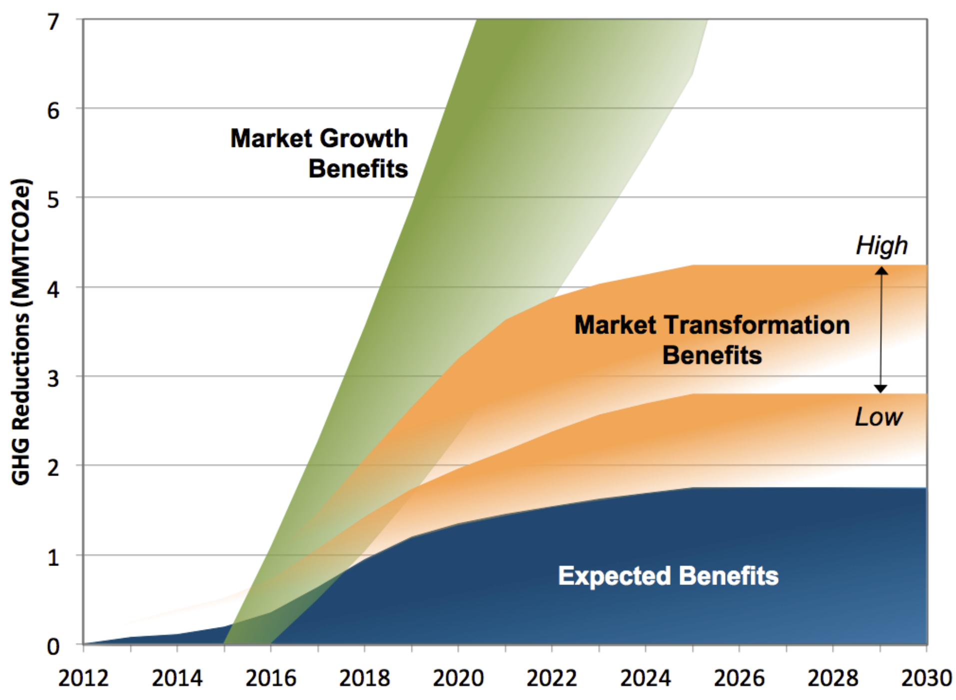
Benefit Category	**GHG Reductions** (Thousand Metric Tonnes CO2e)			**Petroleum Fuel Reductions** (million gallons)		
	2015	**2020**	**2025**	**2015**	**2020**	**2025**
Expected Benefits						
Fueling Infrastructure	63.6	464.9	469.6	16.4	85.4	86.0
Vehicles	84.1	461.6	859.4	20.7	62.4	109.1
Fuel Production	39.1	416.7	416.7	3.5	41.0	41.0
TOTAL	186.8	1,343.1	1,745.7	40.7	188.8	236.1
Market Transformation Benefits						
High	467.6	1,864	2,502.0	68.0	247.4	330.1
Low	338.8	628.9	1,063.4	22.3	55.1	102.5
Required Carbon Market Growth						
High	-	6,397	15,189	-	665.4	1,959
Low	-	2,333	6,375	-	237.2	957.3

Source: NREL

Market growth benefits are developed to reflect the trajectory of future carbon reduction trends required to meet long-term GHG reductions goals, such as the 80 percent reduction below 2005 levels by 2050. The rate at which these reductions must be achieved in the near term (that is, 2015-2025) is uncertain and is therefore represented by high and low cases for estimated reductions within the 2025 time frame. These rates of growth in GHG reductions are based upon scenario trends derived from the California Air Resources Board *Vision for Clean Air* study, with results from that study shifted out to later years, assuming strong growth will occur in the 2016-2018 time frame. These trends are indicative of the required combined effect of all statewide policies and initiatives to reduce GHG emissions in the transportation sector, including ARFVTP activities. Market growth GHG reduction benefits are superimposed on top of expected and market transformation GHG reduction benefits in Figure ES-1. As indicated, the sum of expected and high-case market transformation GHG reduction benefits is about 3.2 $MMTCO_2e$ by 2020, suggesting that ARFVTP projects have the potential to make significant contributions toward meeting California's GHG reduction goals. In contrast, the sum of expected and low-case market transformation GHG reductions makes a more modest contribution and trends below the required market growth reduction trend at about 2.0 $MMTCO_2e$ by 2020.

These comparisons reinforce the importance of continued progress to ensure that the influence of ARFVTP projects translate into favorable market conditions for low-carbon transportation technologies. To achieve the market growth trajectory of GHG reductions, significant progress must be maintained by both future ARFVTP projects and other state policies and initiatives.

Figure ES-1: GHG Reductions From Expected, Market Transformation, and Market Growth Benefits



Source: NREL

The combined expected and market transformation benefits shown in Figure ES-1, and indicated quantitatively in Tables ES-2 and ES-3, are based upon detailed calculations at the project and category level for a range of vehicle and fuel technology types. The majority of calculations rely upon data acquired by Energy Commission staff through project descriptions or survey responses from awardees. Where project-level data are not available, estimated or extrapolated values are developed to reflect the successful deployment or potential market influences of specific technologies or processes. The research team anticipates that this analytic framework will provide more consistent and robust benefit estimate results as additional data continue to be collected at the project level and influences on future market trends are better characterized to reflect observed market outcomes.

Results for the market transformation benefits category are summarized in Table ES-3. The table indicates GHG reduction results for high and low cases for projects that influence future markets by reducing vehicle prices, reducing zero-emission vehicle production costs by accelerating industry experience, and catalyzing deployment of next-generation advanced truck and fuel production technologies. The table also indicates high and low petroleum fuel-use reductions for the same project categories. GHG reductions due to increased industry experience in producing zero-emission vehicles make a relatively small contribution in the high case (about 10 percent), while next-generation fuels contribute roughly 40 percent of total market transformation GHG reductions in the high case.

The benefit estimation framework employed in the present study depends highly upon data provided on the technological and market potential of specific ARFVTP projects. In many cases these data are limited, and additional assumptions are required to develop consistent GHG and petroleum fuel reduction benefits. In most cases, these estimates do not reflect the general technological performance or market potential of the technologies funded by ARFVTP. Instead, the estimates are a consistent representation of expected benefits and market influences based upon the best available data from specific ARFVTP projects. This framework can be improved to better inform future ARFVTP funding and benefit estimation activities with the following enhancements:

- Collect and integrate data on technology-specific deployment effectiveness metrics
- Project evaluation metrics as they might be realized under market success conditions
- Explicitly model competitive dynamics between advanced and incumbent technologies
- Integrate the value of station availability into vehicle market adoption estimates

The present analysis expands and improves upon past ARFVTP benefit estimate efforts but is ultimately limited by the quality and availability of project-level data and indicators of market influence. As additional market experience accumulates and more and better data on ARFVTP projects become available, enhancements to this analytic framework will result in more complete and rigorous benefit estimates.

Table ES-2: Expected GHG Reduction Benefits Through 2025

Benefit Category	Project Class	GHG Reductions (thousand tonnes CO2e)			Petroleum Reductions (million GGE/DGE)		
		2015	2020	2025	2015	2020	2025
Refueling Infrastructure	Biodiesel	5.0	70.5	70.5	0.5	8.5	8.5
	Natural and Renewable Gas	29.7	304.3	304.4	7.0	39.1	39.2
	Electric Chargers	25.4	58.1	62.7	3.2	7.3	7.9
	E85 Ethanol	2.3	11.1	11.1	5.6	27.2	27.2
	Hydrogen	1.2	20.9	20.9	0.2	3.3	3.3
Vehicle	Light Duty BEVs and PHEVs	0.1	3.0	2.0	0.0	0.4	0.3
	Electric Commercial Trucks	0.0	3.0	1.4	0.0	0.4	0.2
	Gas Commercial Trucks	82.0	33.3	4.8	20.5	8.3	1.2
	Manufacturing	2.0	422.4	851.2	0.2	53.3	107.5
Fuel Production	Biomethane	1.6	42.7	42.7	0.1	3.7	3.7
	Diesel Substitute	37.5	277.5	277.5	3.4	26.8	26.8
	Gasoline Substitute	0.0	96.5	96.5	0.0	10.4	10.4
Total		**186.8**	**1,343.1**	**1,745.7**	**40.7**	**188.8**	**236.1**

Source: NREL

Table ES-3: Market Transformation Benefits – GHG Reductions

Market Transformation Influence	Case	GHG Reductions (thousand tonnes CO2e)			Petroleum Reductions (million GGE/DGE)		
		2015	2020	2025	2015	2020	2025
Vehicle Price Reductions	High	309.8	563.8	720.4	36.9	70.1	104.6
	Low	304.4	457.5	574.2	18.5	31.2	45.9
ZEV Industry Experience	High	34.2	145.7	245.5	4.5	19.3	36.9
	Low	28.6	122.0	205.6	3.8	16.2	30.9
Next Generation Trucks	High	123.6	494.5	494.5	26.6	106.6	106.6
	Low	5.79	23.1	23.1	-	5.2	5.2
Next Generation Fuels	High	-	659.7	1,041.6	-	51.4	81.9
	Low	-	26.3	260.4	-	2.6	20.5
Total	**High**	**467.6**	**1,863.6**	**2,502.0**	**68.0**	**247.4**	**330.1**
	Low	**338.8**	**628.9**	**1,063.4**	**22.3**	**55.1**	**102.5**

Source: NREL

CHAPTER 1: Introduction

Several challenges and barriers impede early markets for alternative and renewable fuels and vehicles. Support from government agencies and industry initiatives is justified based upon the social and environmental benefits accrued as a result of greenhouse gas emission reductions, increased energy security from reduced reliance on petroleum-based fuels, reductions in criteria air emissions, savings to consumers on fuel costs, and resulting direct or indirect contributions to California's regional economy. An extensive literature exists on the lack of private sector investment in technology innovation and the social and environmental benefits of advanced and renewable fuel and vehicle technologies. A recent review of technologies to reduce greenhouse gas (GHG) emissions in the light-duty vehicle (LDV) sector by the National Academy of Sciences concluded that investments in the deployment of technologies during the early market introduction phase result in social benefit returns that are multiple times larger than the initial investments.[1] While the cost per unit of reducing GHG emissions in the transportation sector may be higher than in other sectors, such as building efficiency or electricity production, there is a strong need for diversification and innovation in the transportation sector due to expected global growth, the energy security implications of petroleum fuels dominating the sector, continuing public health impacts due to poor air quality in major metropolitan areas, and the availability of relatively low-cost but increasingly higher-carbon unconventional petroleum resources.[2]

An explicit goal of the Alternative and Renewable Fuel and Vehicle Transportation Program (ARFVTP) is to make strategic investments in a broad portfolio of technologies with the goal of transforming transportation markets to favor adoption of sustainable transportation technologies. To be effective, these investments must take into account a broad range of market transformation dynamics, as a well as a complex technology innovation system underlying various key fuel production and vehicle technologies.[3] A review of the market transformation process and key aspects of energy technology innovation systems is required to provide context for understanding the benefits and potential effectiveness of ARFVTP investments. These topics are reviewed in the sections below, followed by a summary of California goals and policies

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1 NRC (2013). *Transitions to Alternative Vehicles and Fuels Committee on Transitions to Alternative Vehicles and Fuels*; Board on Energy and Environmental Systems; Division on Engineering and Physical Sciences, National Research Council. Washington, D.C.: The National Academies Press, http://www.nap.edu/catalog.php?record_id=18264.

2 Greene, D. L., Hopson, J. L., and Li, J. (2003). *Running Out of and Into Oil: Analyzing Global Oil Depletion and Transition through 2050.* Knoxville, TN: Oak Ridge National Laboratory, Oak Ridge, TN, and the National Transportation Research Center.

3 Grübler, A., Aguayo, F., Gallagher, K., Hekkert, M., Jiang, K., Mytelka, L., et al. (2012). Policies for the Energy Technology Innovation System (ETIS). *Global Energy Assessment: Toward a Sustainable Future*, 1665–1743.

related to the transportation sector and an overview of the general method of estimating program benefits. Chapters 2, 3 and 4 review three categories of benefits: expected benefits, market transformation benefits, and required carbon market growth benefits. The final chapter summarizes results and recommendations to enhance the benefit estimation method.

1.1 Market Transformation

Traditional discussions of market transformation efforts address energy efficiency technologies or practices that are economically viable today and have sufficient payback periods, but are inhibited in market growth due to several market barriers or market failures. These barriers may include lack of information on the part of consumers (or producers), limited product availability or diversity, and price distortions.[4] Brown (2001) discussed the "interest rate gap" associated with a capital market barrier, resulting from energy producers having much lower effective discount rates than consumers of energy.[5] The low priority placed on energy costs within household, commercial, and even industrial facility budgets is an additional barrier.[6,7] Market failures or imperfections include misplaced incentives for key decision makers, fiscal and regulatory policies that penalize efficiency measures, failure to internalize external costs such as pollution or health impacts, and undervalued public goods such as education, training, and research and development (R&D).[8,9]

For consumers to overcome these barriers and market imperfections would require significant effort, information, and decision analysis capacity. Various transaction costs effectively serve as high discount rates for energy efficiency investments. Public outreach and education are means of reducing these barriers. Another important focus of market transformation efforts is support for producers and suppliers to reduce market entry costs, accelerate deployment rates, and achieve economies of scale and learning-by-doing to bring down the costs of new technologies. Market transformation efforts therefore must take into account multiple complex influences on market success, including consumer perception and behavior, producer disincentives, market

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4 Geller, H. and S. Nadel (1994). "Market Transformation Strategies to Promote End-Use Efficiency." *Annual Review of Energy and the Environment* 19: 301-346.

5 Brown, M. A. (2001). "Market failures and barriers as a basis for clean energy policies." *Energy Policy,* 29(14), 1197–1207.

6 Ross, M. (1986). "Capital budgeting practices of twelve large manufacturers." *Financial Management*, 15(4), 15–22.

7 Laitner, J. A., DeCanio, S. J., Koomey, J. G., and Sanstad, A. H. (2003). "Room for improvement: increasing the value of energy modeling for policy analysis." *Utilities Policy*, 11(2). doi:10.1016/s0957-1787(03)00020-1.

8 Nemet, G. F. and D. M. Kammen (2007). "U.S. energy research and development: Declining investment, increasing need, and the feasibility of expansion." *Energy Policy* 35(1): 746-755.

9 Gallagher, K. S., Grübler, A., Kuhl, L., Nemet, G., and Wilson, C. (2012). "The Energy Technology Innovation System." *Annual Review of Environment and Resources,* 37(1), 137–162. doi:10.1146/annurev-environ-060311-133915.

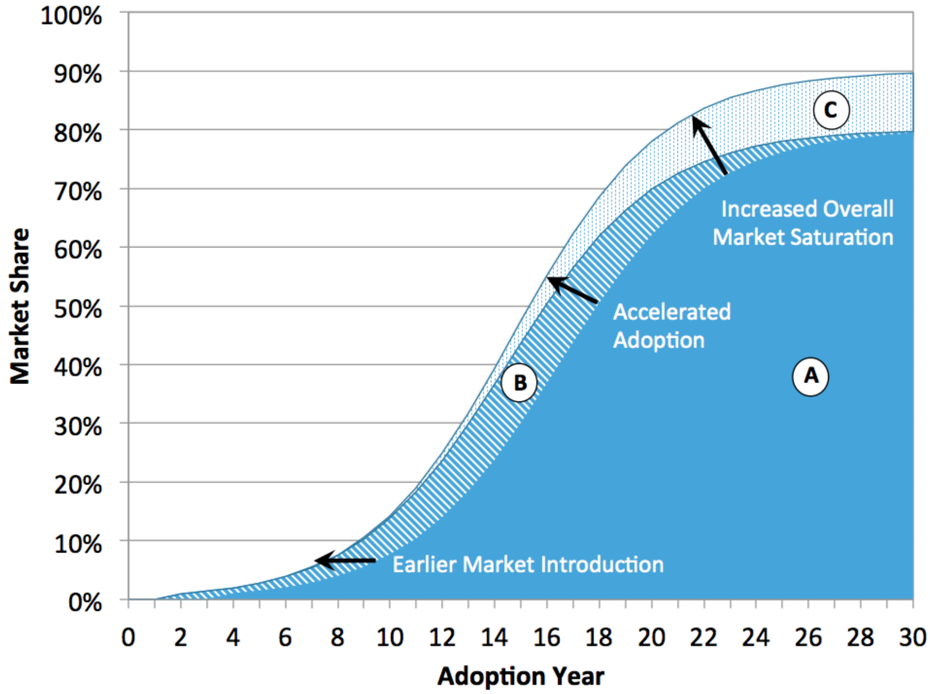
entry barriers, fiscal policy, regulatory influences, competition, and technology innovation. The California Energy Commission has significant experience addressing these and other barriers associated with more energy-efficient technologies.

The ARFVTP is uniquely charged to support a portfolio of sustainable transportation technologies with both near- and long-term market potential. As traditionally applied to energy efficiency technologies, market transformation is often described as reducing barriers or fixing market imperfections for technologies that would otherwise prove to be competitive in the market (Geller and Nadel 1994). Increasing consumer awareness would, for example, result in more rational decision-making and calculation of more realistic payback periods for efficient appliances. Expenditures on such programs are justified because it is accepted that more efficient appliances have favorable payback times today. In contrast, some technologies supported by ARFVTP have only modest market potential in the near term but significant potential over the long-term. In addition, significant network externalities exist for new fueling systems that need to be deployed to serve across large geographic regions (Greene 2013).

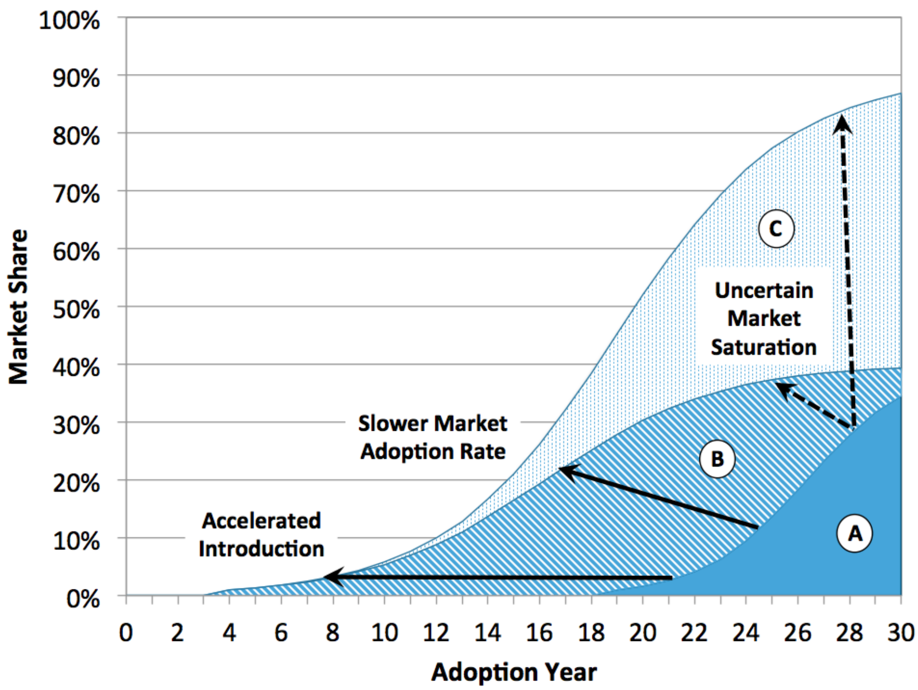
The distinction between these two types of market transformation is depicted in Figure 1. The top figure (a) indicates the more traditional situation for cost-effective energy efficiency technologies, where area "A" indicates adoption growth reaching 80 percent market share over 30 years for a hypothetical technology receiving no policy support. With support from market transformation, market introduction can be earlier, area "B," and can even result in accelerated adoption rates and higher overall market saturation, area "C." This traditional approach, therefore, results in a marginal increase in benefits achieved by introducing the new technology more quickly and perhaps across a larger fraction of the market.

A "transitional" view of the market transformation dynamics associated with a different technology with long-term market potential is depicted in the bottom figure (b), with the new technology achieving only significant market share after market conditions become favorable over time, shown as area "A." Examples for this delayed adoption could be battery electric vehicles (BEVs) or fuel cell electric vehicles (FCEVs) becoming favorable when both petroleum prices remain consistently high and technology costs decline through slow and steady improvements (Greene 2013). For transitional market transformation support, the introduction of the technology could occur much earlier as a result of policy support mechanisms but subsequently grow at a slower rate due to less favorable market conditions, shown as area "B." Alternatively, if market conditions become favorable more quickly (for example, petroleum prices climb, or robust carbon policies are implemented), the new technology could attain a higher level of market saturation. The ultimate market saturation level depends upon a large number of uncertain and interdependent factors and is depicted as the difference between areas "B" and "C."

Figure 1: Market Share Shifts for Traditional (a) and Transitional (b) Market Transformations



(a)



(b)

NOTE: Figure (a) represents market transformation support for a technology with near-term market potential, and (b) applies to a technology with otherwise long-term market potential. (Derived from Geller and Nadel 1994)

1.2 Effectiveness Metrics and Technology Innovation Systems

The benefit estimation method employed in this report is not sufficient to determine the degree to which different ARFVTP investments are effective at reducing GHG emissions or petroleum fuel use. One simple reason for this limitation is that complete and consistent cost-share information is not yet available for all of the projects evaluated. Therefore, of the total benefits estimated for any given project, it is not analytically possible to allocate the portion attributable to funds provided by ARFVTP. For example, if $1 million in ARFVTP funds were awarded to a project that required $3 million funds in total, therefore requiring $2 million in matching funds, it could reasonably be asserted that one-third of the resulting benefits are attributable to ARFVTP and two-thirds to parties providing the balance of funds.

However, even with complete and consistent data on matching funds for each project, multiple factors limit the ability to both estimate future benefits and attribute a portion of those benefits to parties providing funding. Briefly, three key issues are:

- **Uncertainty of future market outcomes.** The expected benefit estimates are relatively optimistic in that they assume each project funding is "successful" in the sense the full utility of the vehicle or facility is achieved and a one-to-one substitution with the incumbent technology is achieved. This assumption depends partially upon future market outcomes and consumer behavior proving favorable to the new technology. For example, for filling stations offering E85 to be fully used, a favorable price differential between E85 and gasoline would be required, as well as increased consumer awareness. The research team assumes that both of these conditions are realized, resulting in full use of funded E85 or compressed natural gas (CNG) stations (after a multiyear ramp-up period). In reality, even with a 50-50 cost share, additional effort may be required to ensure that favorable market conditions are realized, and in the case of a drop in global oil price, even a great effort may not be sufficient. This is a relatively simple example. The market uncertainties around future benefits for complicated projects are greater.
- **Complexity of technology innovation systems.** Technology innovation is complex and unpredictable. Transforming future transportation markets in California requires investments in a range of innovative projects with greater and lesser probabilities of success and large and small long-term benefit potential. Projects with less uncertainty may be more predictable in terms of estimating benefits, but those same projects may have relatively low long-term market impact potential. Some degree of risk must be accepted when investing in technology innovation systems. This inherent risk and diversity of project types complicates the degree to which benefits can be attributed across a portfolio of projects.
- **Variability in market impact timescales.** While some low-cost and low-risk projects are very likely to accrue benefits in the near term, high-risk projects may fail completely or may result in significant benefits over the long term. A simple cost-benefit framework may not be able to generate commensurable effectiveness metrics across a portfolio that includes both low- and high-risk projects with either near- or long-term benefit or market impact potential. Integrated energy assessment models do exist that attempt to

endogenize technology innovation systems, but these models are typically very hypothetical and incapable of integrating empirical data at the project level of detail, and are therefore ill-suited for program evaluation.[10]

1.3 Market Adoption Goals for Vehicles and Fuels in California

California leads the nation in market adoption and policy support for alternative fuels and vehicles. Table 1 summarizes the primary policy objectives, goals, and milestones associated with ARFVTP investment areas.

Table 1: Policy Objectives, Goals, and Milestones

Policy Objectives	Policy Origin	Goals and Milestones
GHG Reduction	AB 32, California Global Warming Solutions Act	Reduce GHG emissions to 1990 levels by 2020 and 80% below 1990 levels by 2050 in California
Petroleum Reduction	California *State Alternative Fuels Plan*	Reduce petroleum fuel use to 15% below 2003 levels by 2020 in California
In-State Biofuels Production	California *Bioenergy Action Plan*	Produce in California 20 percent of biofuels used in state by 2010, 40 percent by 2020, and 75 percent by 2050
Low Carbon Fuel Standard	AB 32	10% reduction in carbon intensity of transportation fuels in California by 2020
RFS2	Energy Policy Act of 2005, Energy Independence and Security Act of 2007	36 billion Gallons of renewable fuel by 2022
Air Quality	Clean Air Act	80 percent reduction in NOx from current levels by 2023
ZEV Mandate	California Executive Order B-16-2012	Accommodate 1 M EVs by 2020 and 1.5 M by 2025 in California

Figure 2 depicts trends in alternative fuel and advanced technology vehicle adoption for three states (California, Texas, and New York) with the largest overall vehicle fleets. Figure 2 compares the CNG-fueled and electric drive vehicle (EVs) adoption rates as a fraction of the total vehicle fleet, including light-, medium- and heavy-duty vehicles[2]. From this figure it can be seen that California has been successful in spurring the adoption of both CNG and EVs, significantly increasing their market penetration (by 0.046 percent and 0.039 percent, respectively) between 2006 and 2011. These increases represent about 10,700 additional CNG vehicles and 6,600 EVs added to service during that period.

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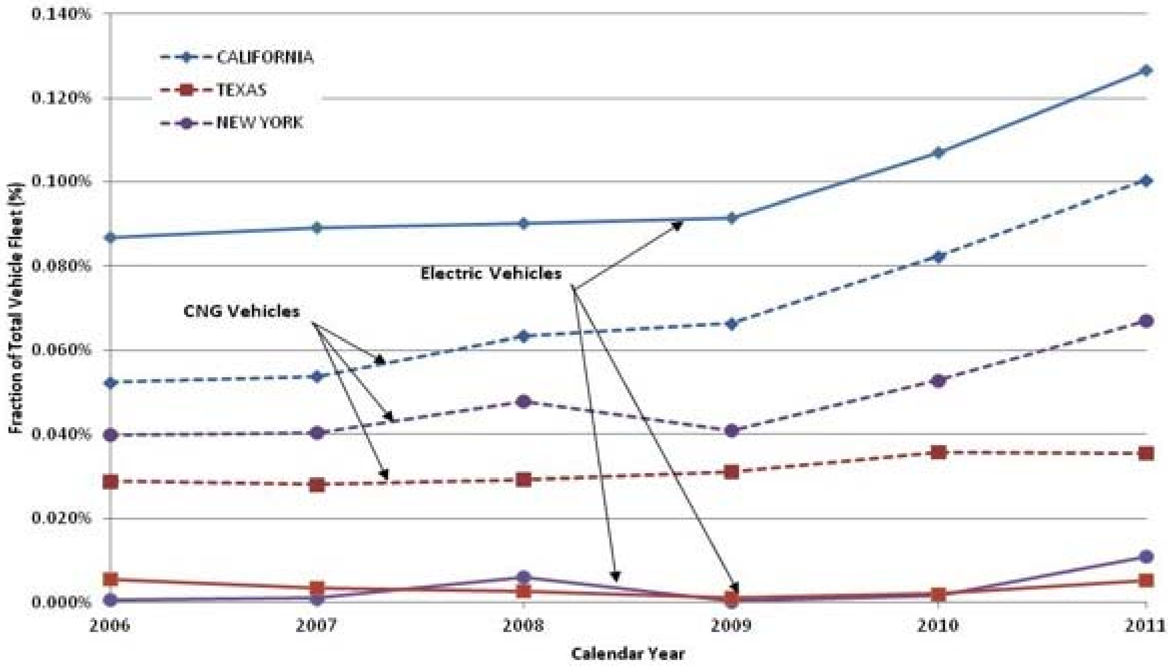
10 Neij, L. (1997). “Use of experience curves to analyse the prospects for diffusion and adoption of renewable energy technology”. *Energy Policy*, 23(13), 1099–1107.

Figure 2: Electric and CNG Vehicles as the Fraction of Total On-Road Light-, Medium-, And Heavy-Duty Vehicles: California, Texas, and New York



Sources:

1. U.S. Department of Transportation, Federal Highway Administration. Highway Statics Series Publications. http://www.fhwa.dot.gov/policyinformation/statistics.cfm Accessed July, 2013.
2. U.S. Energy Information Administration. Renewable & Alternative Fuels, Alternative Fuel Vehicle Data. http://www.eia.gov/renewable/afv/users.cfm Accessed July, 2013.

Though this progress is significant, it is small relative to the overall market and technological momentum in California's transportation market, as well as the momentum of firmly entrenched global automotive and petroleum fuel industries. The $100 million per year in funding provided through ARFVTP has attracted considerable attention from various interested stakeholders, and there are significant expectations as to the benefits that might accrue from allocating these funds to promising technologies and market support activities. However, it must be kept in mind that the transportation vehicle and fuel sectors are large systems with significant technological momentum and highly competitive and mature markets. As a point of reference, consumer expenditures on light-duty vehicles alone in California are on the order of $35 billion-$45 billion per year.[11]

This comparison does not take into account fuel expenditures or expenditures within the medium- and heavy-duty vehicle or other transportation markets. Moreover, it does not account for the significant market power of the global automotive and petroleum fuels industries, and the high level of technological maturity of the majority of their products. Within

11 For the sake of example, consider 1.2 million to 1.5 million LDVs sold per year at an average price of $30,000 per vehicle.

this context, it is essential that ARFVTP funds focus on promising technologies and niche markets, and it is highly unlikely that ARFVTP projects alone will shift California's transportation market to a more sustainable trajectory. This shift will be achieved only with robust and complementary support from other policies and programs, such as those listed in Table 1, as well as support and engagement from key industry stakeholders.

1.4 Benefit Categories and Estimation Method

This report provides guidance on estimating GHG and petroleum fuel reduction benefits associated with projects supported by the ARFVTP. This guidance builds upon previous benefits estimates prepared by the Energy Commission.[12] A significant enhancement to the previous estimation method is the characterization and quantification of four types of benefits, which include various subcategories:

- **Baseline Benefits.** These benefits accrue over time from alternative and renewable transportation technologies deployed because of initiatives, policy influences, or market outcomes unrelated to ARFVTP. These benefits occur over the same time frame as other benefits and may offer some synergies with activities within other benefits types. However, these synergies are not considered essential to the success of projects supported with ARFVTP funds. Benefits from baseline activities, and the potential influence on ARFVTP projects or future market trends, are not explicitly evaluated in this report. These benefits would likely continue to accrue regardless of the influence of ARFVTP activities, all else being equal.
- **Expected Benefits.** These benefits are associated with projects receiving direct support from ARFVTP funds and accrue as advanced vehicles are driven and alternative fuels are consumed. The data used to quantify expected benefits are typically a combination of historical data collected from project managers or other stakeholders and projected data over the anticipated lifetime of the vehicle or fuel system. Projected data are generally estimated with the assumption that the alternative or renewable vehicle or fuel provides an equivalent service as a comparable displaced conventional vehicle or fuel. This implies that the new vehicle or fuel fully replaces the technical utility provided over the lifetime of the displaced vehicle or fuel system. Where empirical data are lacking, these projections are based upon simplified assumptions about the future performance of new vehicles and new fuel systems. Expected benefits may be realized due to the same favorable market conditions that support baseline benefits (for example, a favorable fuel price differential), but the two types are considered mutually exclusive.
- **Market Transformation Benefits.** These benefits are more hypothetical than expected benefits, primarily because they are more uncertain and more difficult to measure. Most of the market transformation benefit estimates in the present report refer to theoretical models of future market adoption dynamics or consumer behavior and may be difficult

12 McKinney, J., C. Smith, A, Freeman, P. Magana, D. Chapman (2011). Benefits Report for the Alternative and Renewable Fuel and Vehicle Technology Program, Report No. CEC-600-2011-SD, December.

to validate with empirical data. In general, these benefits are associated with accelerated market adoption occurring due to one of three distinct influences:

  - *Price Reduction*. A reduction in market entry barriers for new technologies resulting from increased consumer awareness or removal of consumer choice barriers. This is captured, analytically, as a change in the real or perceived price of a technology. Examples include direct rebates for vehicles or increased availability of retail fueling infrastructure.
  - *Production Cost Reduction*. Activities that result in a reduction in the cost to produce or supply a technology. Reduced costs are assumed to translate to reduced market prices, resulting in more favorable future market conditions for advanced and renewable transportation technologies.
  - *Next-Generation Success*. Technologies deployed at the bench, pilot, or demonstration phase, if successful, translate to increased deployment at larger scales and in a greater number of units. Examples include fuel production processes and advanced truck demonstrations.

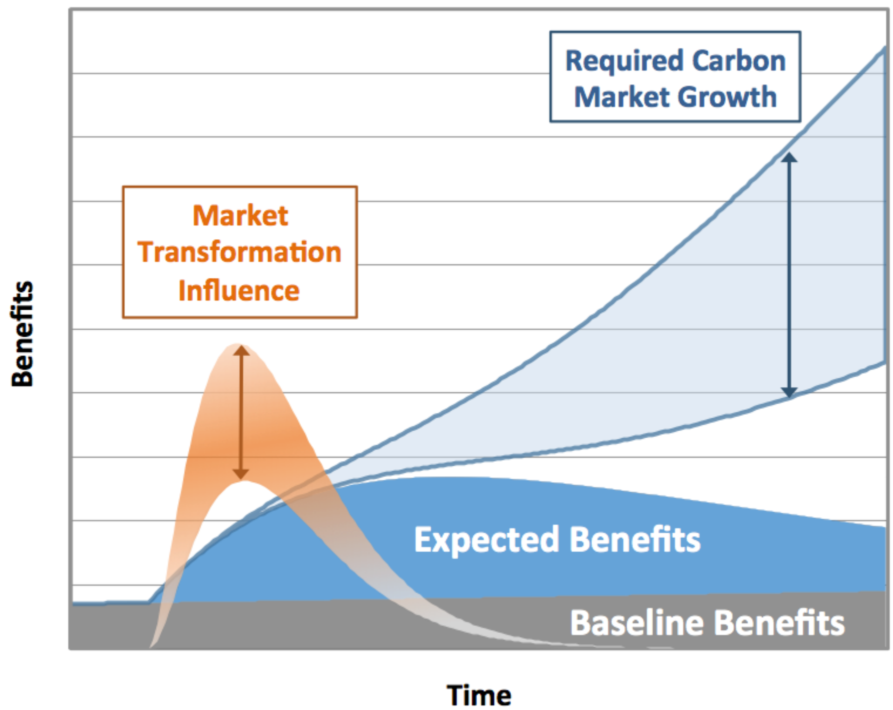
- **Required Carbon Market Growth Benefits:** These benefits are associated with projected market trends comparable to those required to meet deep GHG reductions in the transportation sector by 2050. These benefits are uncertain due to the range of possible ramp-up rates that could possibly lead to future compliance with deep GHG reductions over the long term. However, regardless of ramp-up rates in the near term, required carbon market growth benefits (referred to simply as *market growth benefits*) increase to very large scales within the time frame of the present analysis.

This report focuses on expected benefits and market transformation benefits. In some respects baseline benefits and market growth benefits serve as conceptual guidelines to delineate between benefits directly associated with ARFVTP activities (in other words, expected benefits) and future market growth trends that ARFVTP and other California efforts must work toward achieving (that is, market growth benefits).

Figure 3 illustrates the general relationships between these various benefit types as they might be realized over time. The schematic is not intended to represent any particular vehicle-fuel combination. Baseline benefits are shown increasing slowly and linearly across the bottom of the figure and are realized due to market growth likely to occur in the absence of ARFVTP or other state or federal programs. Expected benefits are indicated as a rapid increase in total benefits as new vehicles and fuels are introduced into the market. These benefits would decline over time as market success is achieved and additional funding is no longer required. Vehicles funded directly would be used less often as they age and eventually replaced, and fuel systems funded directly would be upgraded through new market-driven investments and eventually retired. These two benefit types are shown as being additive in Figure 3.

Sustained market growth is an explicit goal of ARFVTP and other ongoing initiatives and policies supporting GHG reductions and energy security in California. The required carbon market growth benefits indicated in Figure 3 represent a success case, with advanced and renewable fuels and vehicles successfully competing in the market without substantial monetary government support. These market growth benefits are indicated as a range of high and low market growth trends. These two trends are intended to bracket possible rates of growth that would result in compliance with meeting long-term GHG reduction goals, resulting in both climate stabilization benefits and other co-benefits such as reduced reliance on petroleum fuels. The lower bound growth trend would need to accelerate more quickly over time to meet long-term goals, while the upper bound growth trend would saturate or stabilize sooner at a high market share. As market growth benefits increase in scale, support from ARFVTP activities will tend to play a smaller role in the market success of advanced and renewable fuels and vehicles, and expected benefits would decline over time.

Figure 3: General Types of Benefits as a Function of Time



Market transformation benefits are the conceptual link between expected benefits and long-term market growth benefits. As suggested in Figure 3, market transformation activities influence market dynamics during the early phases of ARFVTP project execution, especially in projects that increase refueling availability, raise consumer awareness, or decrease market price differentials (for example, vehicle rebates). Reducing production costs and scaling technologies for next-generation deployment can also influence competition in early niche markets. This near-term influence translates to long-term market growth. Analytically, the present analysis attempts to estimate this near-term market influence and then quantify the benefits over time resulting from a change in market conditions. The term *market transformation* suggests that as additional units are deployed and cost differentials become smaller, demand will increase, new investments will become market-driven, and factors such as limited refueling availability will becomes less of a market barrier for average consumers.

Several projects supported by ARFVTP will result in additional benefits that are not quantified in this report. Examples are benefits that would accrue due to outreach, education, standards development, workforce training, and policy development support. Though these additional benefits may be substantial, they are difficult to quantify due to unclear relationships between cause and effect. The expected and market transformation benefits estimation results are therefore only a subset of total ARFVTP benefits anticipated. On the other hand, most assumptions about future use or deployment of technologies supported by ARFVTP are somewhat optimistic in terms of assuming one-to-one substitution of the service or technical performance of incumbent technologies.

Table 2 reviews the four types of benefits estimated in the present report and provides a brief description of the method used to estimate each type. Chapters 2, 3, and 4 provide additional detail on these methods and benefit estimate results. Chapter 5 summarizes the results and discusses methodological improvements that could be made to better capture the benefits of future ARFVTP activities as more data on technology cost and performance and market dynamics are collected over time.

Table 2: Benefit Category, Estimation Method, and Main Data Type and Source

BENEFIT CATEGORY	ESTIMATION METHOD	DATA TYPES AND SOURCES
Baseline Benefits. Occurring without ARFVTP support.	State-level data reported by EIA on alternative fuel vehicles and use	Empirical data from EIA, CEC, DMV, Polk.
Expected Benefits. Direct investments to increase units deployed or fuel production capacity installed.	Fuel displacement and GHG reductions based upon ARFVTP project-level data and projected use or demand	Empirical data from ARFVTP projects; 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 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 (NRC 2013); planned deployments by urban area
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 Benefits. 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

CHAPTER 2: Expected Benefits

A shift in transportation systems from reliance on petroleum toward low-carbon alternative fuels and advanced vehicles will take time and require substantial investments. California's shift to such a system is being driven in part by state and federal policies intended to address energy security, environmental considerations such as GHG emissions, and economic goals such as workforce training and rural development. The Energy Commission's strategic goal is to provide a wide array of funding to help foster a dynamic market so that ARFVTP funds spur additional investments and private sector support for emerging technologies. Energy Commission investments are small relative to overall investments in the energy sector, but they are a critical component of investments in areas such as electric, fuel cell, and natural gas vehicles; low-carbon fuel production technologies; and alternative fuel retail infrastructure. Given the diversity of projects supported by ARFVTP, the availability of data for estimating benefits varies significantly. This chapter focuses on a subset of total ARFVTP projects for which sufficient data are available to estimate expected benefits with some degree of certainty. As more project-level data are collected, this category of expected benefits will increase and become both more complete and more rigorous.

As of March 31, 2014, some 274 projects had been funded by ARFVTP, representing a total investment of $487.8 million since 2009. As of March 31, 2014, sufficient and appropriate data to serve as a basis to estimate either expected or market transformation benefits (or both) were available for 207 of these projects, representing $426.1 million or about 87 percent of total funding allocated since 2009. Of projects with available data, 178 projects, representing $351.3 million of the $487.8 million (72 percent) have been evaluated for expected benefits. Some $348.2 million in funded projects, or 71 percent of the $487.8 million, are evaluated for market transformation benefits, discussed in Chapter 4. Table 3 reviews ARFVTP projects funded as of March 31, 2014, and, as indicated in Table 4, various projects have been evaluated in both categories, with the benefits from the expected and market transformation categories presented as being additive.

The sections below review the general approach used to make expected benefit calculations for four main categories of projects: (1) electric drive vehicles and fueling infrastructure, (2) gaseous fuel (NG and LPG) vehicles and fueling infrastructure, (2) biofuels (including liquid and gaseous fuels), and (4) hydrogen refueling infrastructure. Expected benefits are reported as petroleum fuel-use reductions, GHG emission reductions, and criteria air pollutant reductions, where applicable. All expected benefit calculations can be tied back to data provided through a project-level survey administered by Energy Commission staff and completed by awardees. The following section provides an overview of the general analytic approach, and subsequent sections review results for each of the main technology categories.

2.1 Methods and Analytic Approach

The research team constructed a model to estimate expected benefits in the form of reductions in petroleum use, GHG emissions, and select air pollutants for projects supporting electric-drive vehicles. The results reported in the *2011 Benefits Report* are not directly comparable to these expected benefit results, due to revisions in method, new data sources, and reorganization of how different benefits are categorized. For example, the 2013 benefits analysis uses an alternative source for air pollutant calculations (that is, VISION model)[13]. The present results also account for a new target year (2025).

2.1.1 Projects Analyzed

The Energy Commission's ARFVTP spending focuses on the project classes outlined in Table 3, including the three general categories of fueling infrastructure, vehicles, and fuel production. The research team evaluated expected benefits for 178 of the 274 projects. In cases where projects are evaluated in terms of both types of benefits, market transformation benefits are considered additive to expected benefits. Market transformation benefits are reviewed in Chapter 3. Figure 4 illustrates the breakdown of projects with expected program benefits. The breakdowns of projects by total number and total funding are both included. Frame (a) shows projects by broad funding categories; Frame (b) shows projects by the alternative fuel system supported by the project.

The pie charts show a divergence between the number of projects funded and the total funding for a particular project category. Frame (a) shows that fueling infrastructure is disproportionality represented by the number of projects funded by the Energy Commission. In contrast, the portion of funding for each project category is much more proportionally distributed than the number of projects would imply. Frame (c) shows that gas and electricity are the major fuel technologies supported by the Energy Commission's ARFVTP, as measured by both funding amounts and the number of projects funded.

2.1.2 Model Construction

The estimated benefits model calculates the direct effects of reducing GHG and petroleum fuels by using alternative fuels and driving advanced vehicles. Indirect effects, such as land-use change and petroleum price rebound effects due to the use of biofuels, are generally beyond the scope of this assessment. The one exception is that life-cycle GHG emissions and land use related GHG emissions for select biofuels are estimated to parallel California Air Resources Board's (ARB) Low Carbon Fuel Standard (LCFS).[14]

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13 Argonne National Laboratory. 2013. VISION 2013 AEO Base case http://www.transportation.anl.gov/modeling_simulation/VISION/.

14 ARB. 2012. *Final Regulation Order.* Table 5. EER Values for Fuels Used in Light- and Medium-Duty, and Heavy-Duty Applications. Sacramento. 107 pp. www.arb.ca.gov/fuels/lcfs/CleanFinalRegOrder112612.pdf..

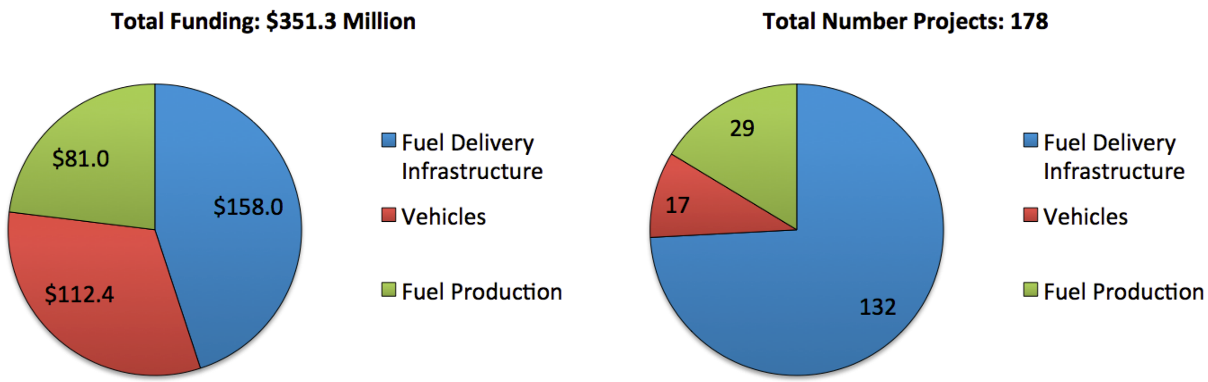
Table 3: ARFVTP Award Categories and Amounts Through March 31, 2014

Fuel Type	Funding Activity	Amount ($ millions)	No. of Awards	Total ($ millions)
Electric Drive	Charging Infrastructure	$38.59	63	$124.83
	Vehicle Deployment Incentives	$48.05	4	
	Light-, Medium- and Heavy-Duty Advanced Vehicle Demonstration	$34.51	11	
	PEV Regional Readiness	$3.68	16	
Hydrogen	Hydrogen Fueling Infrastructure	$82.79	15	$89.50
	Fuel Standards Development	$4.00	1	
	Fuel Cell Bus Demonstration	$2.41	1	
	Regional Readiness	$0.30	1	
Natural Gas	Vehicle Deployment Incentives	$33.37	4	$56.87
	Medium- and Heavy-Duty Advanced Vehicle Demonstration	$6.34	2	
	Fueling Infrastructure	$17.16	47	
Propane	Vehicle Deployment Incentives	$7.30	2	$7.30
Biofuels	Biomethane Production	$38.89	12	$111.20
	Diesel Substitutes Production	$34.08	13	
	Gasoline Substitutes Production	$12.99	5	
	Sustainability Research	$2.10	2	
	E85 Fueling Stations	$16.45	4	
	Upstream Diesel Substitutes Infrastructure	$3.98	4	
	Medium- and Heavy-Duty Advanced Vehicle Demonstration	$2.71	1	
Manufacturing	Manufacturing Facilities and Equipment	$57.45	21	$57.45
Workforce Training/Dev.	Workforce Training and Development	$23.30	30	$23.30
Program Support	Technical Assistance and Analysis	$17.30	15	$17.30
Total		**$487.76**	**274**	**$487.76**

Source: NREL analysis.

Figure 4: Projects Included in Expected Benefits Category

(a) Expected benefit projects by broad funding categories



(b) Expected benefit projects by fuel system supported

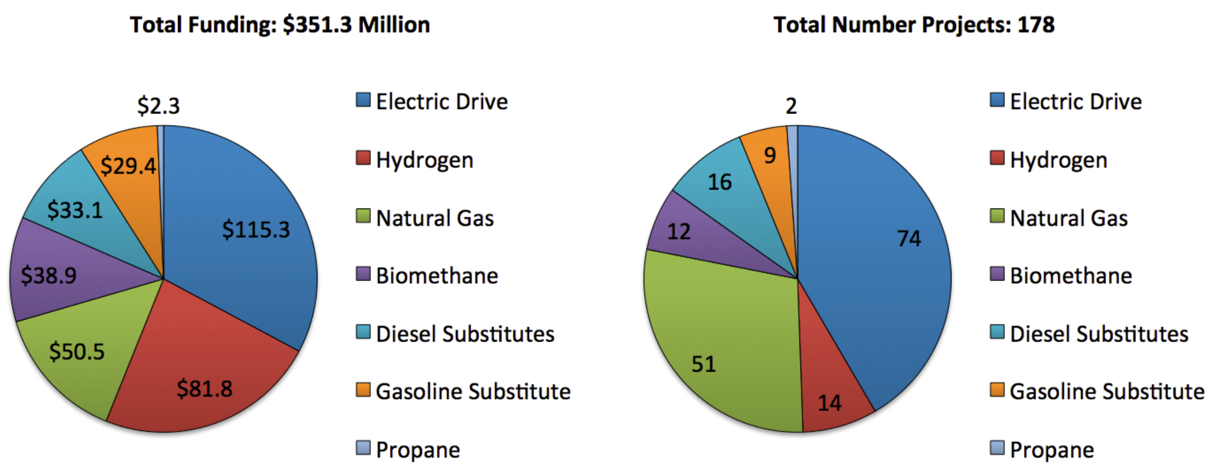


Table 4: Awards Compared to Projects Evaluated by Benefit Type

Project Categories	Fuel Class or Sub Class	Awards to 3/14		Projects Evaluated in Benefits Analysis			Benefit Type Estimated	
		($M)	No. Awards	($M)	No. Awards	Number Units	Expected	Market Transformation
Fuel Delivery Infrastructure								
Electric Drive Charging Infrastructure	Electric Drive	$38.6	63	$38.6	63	20 Level 1 7800 Level 2 119 DCFC	▯ ▯	▯ ▯
Hydrogen Fueling Infrastructure	Hydrogen	$82.8	15	$81.8	14	48 Stations	▯	▯
Natural Gas Fueling Infrastructure	Natural Gas	$17.2	47	$17.2	47	51 Stations	▯	-
E85 Fueling Stations	Gasoline Substitute	$16.5	4	$16.5	4	100 Stations	▯	-
Upstream Infrastructure	Diesel Substitute	$4.0	4	$4.0	4	6 Facilities or Expansions	▯	-
Hydrogen Fuel Standards Development	Hydrogen	$4.0	1	-	-	-	-	-
Fuel Delivery Infrastructure Subtotal		**$163.0**	**134**	**$158.0**	**132**			
Vehicles								
Light-Duty Incentives, CVRP	Electric Drive	$44.1	3	$44.1	3	21,462 Rebates	▯	▯
Medium- Heavy-Duty Incentives, HVIP	Electric Drive	$4.0	1	$4.0	1	160 vehicles	▯	-
Natural Gas Vehicle Deployment Incentives	Natural Gas	$33.4	4	$33.4	4	1038 vehicles	▯	-
LPG Vehicle Deployment Incentives	Propane	$7.3	2	$2.3	2	515 vehicles	▯	-
Light-Duty Demonstration	Electric Drive	$0.6	1	$0.6	1	50 LDVs	▯	-
Medium- and Heavy-Duty Vehicle Demonstration	Electric Drive	$33.9	10	$33.9	10	Various[1]	-	▯
Fuel Cell Bus Demonstration	Hydrogen	$2.4	1	$2.4	1	1 bus	-	▯
Medium- and Heavy-Duty Vehicle Demonstration	Natural Gas	$6.3	2	$6.3	2	2 natural gas engine demos	-	▯
Medium- and Heavy-Duty Vehicle Demonstration	Gasoline Substitute	$2.7	1	$2.7	1	1 hybrid E85 powertrain	-	▯
Component Demonstration	Hydrogen	$1.6	2	$1.6	2	6 vans, 1 bus	-	▯
Component Demonstration	Electric Drive	$27.8	13	$27.8	13	Various[2]	-	▯
Vehicle Manufacturing	Electric Drive	$28.1	6	$28.1	6	Various[3]	▯	▯
Vehicles Subtotal		**$192.1**	**46**	**$187.1**	**46**			

Fuel Production								
Bench Scale & Feasibility	Biodiesel	$5.0	1	-	-	-	-	-
Commercial Production	Biomethane	$34.5	9	$34.5	9	-	□	□
Bench Scale & Feasibility	Biomethane	$4.4	3	$4.4	3	-	□	□
Commercial Production	Diesel Substitutes	$26.4	9	$26.4	9	-	□	□
Bench Scale & Feasibility	Diesel Substitutes	$2.7	3	$2.7	3	-	□	□
Commercial Production	Gasoline Substitute	$10.9	3	$10.9	3	-	□	□
Bench Scale & Feasibility	Gasoline Substitute	$2.1	2	$2.1	2	-	□	□
Fuel Production Subtotal		**$86.0**	**30**	**$81.0**	**29**			
Other								
PEV Regional Readiness	Electric Drive	$3.7	16	-	-	-	-	-
Regional Readiness	Hydrogen	$0.3	1	-	-	-	-	-
Sustainability Research	Biofuels	$2.1	2				-	-
Workforce Training and Development	Workforce Training/Dev.	$23.3	30	-	-	-	-	-
Technical Assistance and Analysis	Program Support	$17.3	15	-	-	-	-	-
Other Subtotal		**$46.7**	**64**	-	-			
TOTAL		**$487.8**	**274**	**$426.1**	**207**			

Notes: (1) 4 HD hybrid hydraulic delivery trucks, 1 range-extender MD truck demo, 5 HD truck retrofits to PHEV, 1 class 8 hybrid natural gas truck, 1 all electric fleet at Air Force Base, 1 diverse fleet of 378 vehicles, 1 prototype class 4 all-electric, feasibility and testing for 1 truck manufacturing facility, 1 CLEAN Truck Demo Program, 8 HD truck retrofits to pantograph system; (2) 3 lithium battery production/assembly processes, 1 electric motorcycle powertrain, 2 battery management/communication systems, 3 electric drive manufacturing and assembly processes, and 4 electric drive demonstration projects including 14 MD trucks, 17 class 6 trucks, 6 schools buses, and 7 walk-in vans; (3) 1 new production line for electric motorcycle, 1 BEV manufacturing and assembly expansion, 1 new manufacturing facility for M/HD BEVs, 1 manufacturing expansion for range-extended MD trucks, 1 pilot production line for flexible all-electric platform, and 1 pilot production line for powertrain control systems.
Source: NREL analysis.

Petroleum reduction calculations for vehicles, vehicle manufacturing, fueling infrastructure, and fuel production projects are each calculated based on different methods. The research team based petroleum reduction calculations on a combination of data provided directly by Energy Commission staff and original research for some evaluated projects. GHG emissions reduction estimates are based on estimated petroleum use reductions calculated within the model and GHG emission factors taken from life-cycle assessment models (for example, CA-GREET).[15] Air pollutant emission reductions are calculated based on estimated vehicle miles traveled (VMT) and emission factors (grams per mile) taken from VISION.[16] Air pollutant emissions are developed primarily for electric-drive vehicles, given that tailpipe emissions from gaseous fuels and biofuels are (or will likely be, under future regulatory conditions) comparable to those from conventional fuels.

The model developed for analysis of expected benefits is organized around annual petroleum use reduction estimates. Reduced petroleum use due to the funding of alternative vehicles is calculated based on petroleum fuel use in the vehicle(s) likely to be replaced by the alternative vehicle. Petroleum use in displaced vehicles is estimated based on the expected fuel economy, lifespan, annual VMT (declining with vehicle age), and rates of vehicle retirements (also called scrappage rates) across a fleet of vehicles. Table 5 lists the replaced vehicle profiles used in annual petroleum use reduction calculations. Table 6 lists rates of VMT depreciation used in each year of the life of a vehicle. These VMT depreciation rates also account for reductions due to vehicle scrappage (that is, only a certain percentage of a fleet of vehicles would still be in operation some N years after the fleet of new vehicles is introduced, with the remainder being retired or scrapped). With the exception of LDV taxis, M/HDVs begin with higher usage rates (19,800 miles per year for MDVs [Class 4-6] and 98,000 miles per year for HDVs [class 7-8]), but combined VMT across the fleet declines more quickly for the larger vehicles after 10 years of operation, reaching only 5 percent of the maximum VMT per year by the 15th year of operation.

15 ARB. 2011. CA-GREET. Version 1.8b. www.arb.ca.gov/fuels/lcfs/lcfs.htm.

16 Argonne National Laboratory. 2013. VISION 2013 AEO Base case http://www.transportation.anl.gov/modeling_simulation/VISION/.

Table 5: Fuel Economy, Lifespan, and Annual Travel of Vehicles Replaced

Type	Make	Fuel Economy	Analysis Lifespan	Maximum Yearly Travel	Source:
		(miles/gal)	(yr)	(VMT/yr)	
LDV	Ford Crown Victoria Taxi	20	16	56,620	A, B
	2012 Nissan Versa	30	16	10,300	C
	2009 Toyota Prius	46	16	10,300	I
Motorcycle	Motorcycle	42.8	16	2,700	H
Fleet	AVG Gasoline Vehicle	27	16	11,530	H
Truck Class 1 - 2a	Honda	31	16	13,469	D, E
	Ford Crown	17.5	16	15,463	D, E
Truck Class 2b - 3	Chevrolet	17.2	16	19,800	D, F
	Ford E-150	17.2	16	19,800	D, F
	Ford E-250	14	16	19,800	D, F
	Ford E-350	10	16	19,800	D, F
	Ford Shuttle	8.5	16	19,800	D, F
	GMC	7.3	16	19,800	D, F
	Glaval	5.6	16	19,800	D, F
Truck Class 4 - 6	Champion	7.3	16	19,800	D, G
	Diamond	7.3	16	19,800	D, G
	El Dorado	7.3	16	19,800	D, G
	Federal Coach	7.3	16	19,800	D, G
	Ford	8.5	16	19,800	D, G
	Goshen	8	16	19,800	D, G
	Greenkraft	8	16	19,800	D, G
	Isuzu	8	16	19,800	D, G
	Krystal	6.6	16	19,800	D, G
	Rockport	6.6	16	19,800	D, G
	Starcraft	6.6	16	19,800	D, G
	Tiffany Coach	6.6	16	19,800	D, G
Truck Class 6	Blue Bird	7	16	19,800	D, G
	Collins	7.3	16	19,800	D, G
	Grech	7	16	19,800	D, G
	Microbird	7	16	19,800	D, G
Truck Class 7 - 8	American LaFrance	2.8	16	98,000	D, G
	Autocar	2.8	16	98,000	D, G
	Capacity	8	16	98,000	D, G
	Crane Carrier	2.8	16	98,000	D, G

	Daimler	5.4	16	98,000	D, G
	Unknown	2.8	16	98,000	D, G
	Freightliner	5.6	16	98,000	D, G
	Unknown ISLG	5.6	16	98,000	D, G
	Kenworth	6.4	16	98,000	D, G
	Mack	2.8	16	98,000	D, G
	Peterbilt	2.8	16	98,000	D, G

NOTES: Sources for each assumption listed below.

A. Taxicab, Limousine, and Paratransit Association. 2009. TPLA Taxicab Fact Book. Rockville. www.tlpa.org/index.cfm.
B. U.S. Department of Energy. 2013. Fuel Economy.gov. Retrieved on May 1st 2013 from www.fueleconomy.gov/feg/Find.do?action=sbs&id=30683.
C. U.S. Department of Energy. 2013. Fuel Economy.gov. Retrieved on May 1st 2013 from www.fueleconomy.gov/feg/PowerSearch.do?action=noform&path=1&year1=2012&year2=2012&make=Nissan&model=Versa&srchtyp=ymm.
D. U.S. Department of Energy. 2012. "Transportation Statistics Data." Table 4-11, pg. 253.
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E. U.S. Department of Energy. 2012. *Transportation Energy Data Book*. Summary Statistics on Demand Response Vehicles. Tables 4.1, 4.3, 4.33, and 5.1.
F. VMT per year assumption based upon MDVs in VISION model, Argonne National Laboratory, available at: http://www.transportation.anl.gov/modeling_simulation/VISION/; American Public Transportation Association. 2011. Public Transportation Fact Book, Washington, D.C., 44pp. www.apta.com/resources/statistics/Documents/FactBook/APTA_2011_Fact_Book.pdf.
G. VMT per year assumption based upon HDVs in VISION model, Argonne National Laboratory, available at: http://www.transportation.anl.gov/modeling_simulation/VISION/; Americas Commercial Transportation Research Co., LLC. 2012. ACT Research. State of the Industry: ACT U.S. Classes 3-8 Used Trucks. Columbus, 20pp. www.actresearch.net/services/publications/state-of-the-industry-act-u-s-classes-3-8-used-trucks.
H. U.S. Department of Transportation. 2013. 2012 National Transportation Statistics. Washington, D.C. pp 253, 254, 256, 257.
I. U.S. Department of Energy. 2014. Fuel Economy.gov. Retrieved on May 23rd 2014 from http://www.fueleconomy.gov/feg/Find.do?action=sbs&id=25987.

Estimating annual petroleum use reductions achieved through vehicle manufacturing uses a similar albeit slightly more complex system. New vehicles enter the vehicle fleet each year through manufacturing, so benefit calculations for each year incorporate the effect of new vehicles produced and all vehicles produced in previous years for a given age of those vehicles.

Table 6: VMT Depreciation Rates of Replaced Vehicles for Every Five Years of Use

Type	Make	Year 1	Year 5	Year 10	Year 15	Year 20	Year 25
LDV	Ford Crown Victoria Taxi	100.0%	85%	58%	33%	16%	6.6%
	2012 Nissan Versa	100.0%	85%	58%	33%	16%	6.6%
	2009 Toyota Prius	100.0%	85%	58%	33%	16%	6.6%
Motorcycle	Motorcycle	100.0%	85%	58%	33%	16%	6.6%
Fleet	New Gasoline Vehicle	100.0%	85%	58%	33%	16%	6.6%
Truck Class 1 - 2a	Honda	100.0%	82%	54%	30%	14%	5.1%
	Ford Crown	100.0%	82%	54%	30%	14%	5.1%
Truck Class 2b - 3	Chevrolet	100.0%	91%	42%	5%	0%	0%
	Ford E-150	100.0%	91%	42%	5%	0%	0%
	Ford E-250	100.0%	91%	42%	5%	0%	0%
	Ford E-350	100.0%	91%	42%	5%	0%	0%
	Ford Shuttle	100.0%	91%	42%	5%	0%	0%
	GMC	100.0%	91%	42%	5%	0%	0%
	Glaval	100.0%	91%	42%	5%	0%	0%
Truck Class 4 - 6	Champion	100.0%	91%	42%	5%	0%	0%
	Diamond	100.0%	91%	42%	5%	0%	0%
	El Dorado	100.0%	91%	42%	5%	0%	0%
	Federal Coach	100.0%	91%	42%	5%	0%	0%
	Ford	100.0%	91%	42%	5%	0%	0%
	Goshen	100.0%	91%	42%	5%	0%	0%
	Greenkraft	100.0%	91%	42%	5%	0%	0%
	Isuzu	100.0%	91%	42%	5%	0%	0%
	Krystal	100.0%	91%	42%	5%	0%	0%
	Rockport	100.0%	91%	42%	5%	0%	0%
	Starcraft	100.0%	91%	42%	5%	0%	0%
	Tiffany Coach	100.0%	91%	42%	5%	0%	0%
Truck Class 6	Blue Bird	100.0%	91%	42%	5%	0%	0%

	Collins	100.0%	91%	42%	5%	0%	0%
	Grech	100.0%	91%	42%	5%	0%	0%
	Microbird	100.0%	91%	42%	5%	0%	0%
Truck Class 7 - 8	American LaFrance	100.0%	77%	28%	6%	0.2%	0%
	Autocar	100.0%	77%	28%	6%	0.2%	0%
	Capacity	100.0%	77%	28%	6%	0.2%	0%
	Crane Carrier	100.0%	77%	28%	6%	0.2%	0%
	Daimler	100.0%	77%	28%	6%	0.2%	0%
	Unknown	100.0%	77%	28%	6%	0.2%	0%
	Freightliner	100.0%	77%	28%	6%	0.2%	0%
	Unknown ISLG	100.0%	77%	28%	6%	0.2%	0%
	Kenworth	100.0%	77%	28%	6%	0.2%	0%
	Mack	100.0%	77%	28%	6%	0.2%	0%
	Peterbilt	100.0%	77%	28%	6%	0.2%	0%

Source: Argonne National Laboratory. 2013. VISION 2013 AEO Base case http://www.transportation.anl.gov/modeling_simulation/VISION/.

Estimated petroleum use reductions benefits of fuel production and fueling infrastructure are based mostly on petroleum reduction data provided directly by Energy Commission staff.[17] Data provided generally indicate throughput and capacity. The one set of infrastructure projects in which petroleum use reductions were estimated is EVSE projects. Petroleum use reduction is estimated based on assumptions about the combination of vehicles (that is, PHEVs and BEVs) supported by EVSE infrastructure and the annual VMT using petroleum that would be displaced by e-miles (miles driven using electric rather than petroleum fuel energy). The number and types of EVSE from each project were used to calculate the number of vehicles supported. The research team relied upon data listed in Table 7 for this calculation. These estimates could be improved upon if project-level data were provided on the number and types of vehicles supported by each EVSE unit supported within each project. Data on the electric miles charged by each vehicle per day, as listed in Table 7, were used to calculate annual e-miles supported by the EVSE projects.

The research team calculated petroleum use reductions due to displaced petroleum vehicle VMT using the expected fuel economy and lifespan of either the average fleet of gasoline vehicles or the specific vehicle type, if that information was available. Petroleum use reductions estimates represent VMT of alternative vehicles supported that would have otherwise been driven using a conventional petroleum fuel vehicle. The lower heating values used to convert survey or other data into consistent energy basis units, either DGE or GGE, are taken from the GREET model and indicated in Appendix A.

Table 7: Near-Term EVSE Assumptions Used to Calculate Petroleum Vehicle Miles Displaced[18]

EVSE Type	Vehicles Charged per Day	Electric Miles Charged per Day per Vehicle
Level 2 -Residential	1	17.2
Level 1 -Commercial	1	7.8
Level 2 -Commercial	6	15.7
DC Fast Chargers	8	14.7

The model incorporates some aspects of the timing of petroleum use reductions into the calculation of annual benefits. ARFVTP projects typically have a start and end date. Based on feedback from Energy Commission staff, it is assumed that fuel production and fueling infrastructure projects start operation nine months before the contract end date and take three years to ramp up to full capacity.[19] Ramp up occurs linearly over that period. It is assumed that fuel production and fueling infrastructure had a lifespan longer than 2025. The lack of fuel

17 Energy Commission.. 2013. Personal communication, October 1, 2013.

18 *Melaina, Marc, Michael Helwig. (National Renewable Energy Laboratory). 2014. California Statewide Plug-In Electric Vehicle Infrastructure Assessment. California Energy Commission. Publication Number: CEC-600-2014-003. Available online at: www.energy.ca.gov/2014publications/CEC-600-2014-003/CEC-600-2014-003.pdf*

19 Energy Commission. 2013. Personal communication, October 1, 2013.

production and fueling infrastructure turnover falling off within the analysis period (2011-2025) means that the lifespan was not relevant in calculating expected benefits.

Conversely, the model assumes alternative fuel vehicles enter the fleet when purchased. Vehicle turnover is important for the estimation of future petroleum-use reductions. Rates of vehicle turnover depend on the assumed lifespan of the petroleum vehicle (see Table 5) replaced. It is optimistically assumed that all new alternative fuel vehicles replace conventional fuel vehicles, rather than other alternative fuel vehicles. However, once alternative fuel vehicles supported by ARFVTP are retired, it is not assumed that a new alternative fuel vehicle will be adopted. Increased vehicle adoption rates in the expected benefits method therefore taper out over time as vehicles are driven less and retired.

Categorization of the fuel pathway of a project is used to match petroleum use reductions estimates with appropriate emission reduction factors (see the following section) for the estimation of annual GHG and air pollutant emission reductions. For fuel production infrastructure, the fuel pathway depends on the biomass feedstock(s) used and biofuel produced. For vehicles and delivery infrastructure, a single likely fuel pathway is assumed for each vehicle or delivery infrastructure, unless otherwise noted in data provided by Energy Commission staff.[20] For example, it is assumed that corn ethanol is provided through most new E85 fueling stations funded by ARFVTP.

Data are aggregated in the model for further calculations after estimating the project-level annual petroleum use, GHG emission, and air pollutant emission reductions. Petroleum use, GHG emissions, and air pollutant emission reduction estimates are combined on the basis of broad project class (for example, vehicles, fueling infrastructure, and fuel production infrastructure), specific project classes, and fuel system (for example, electric, ethanol, biodiesel). Reductions for each year are then displayed in the tables and figures in the sections below. For example, the "diesel substitutes" category includes petroleum and emission reductions from Fischer-Tropsch (FT) diesel, biodiesel, and renewable diesel.[21]

2.1.3 Emission Reduction Factors

The research team compiled life-cycle GHG emissions results for petroleum and alternative fuels from multiple sources to generate a set of GHG emission reduction factors. Table 8 lists the life-cycle GHG emissions of fuel pathways used in this analysis. ARB's energy efficiency ratios (EERs)[22] are applied to each GHG emission factor to calculate GHG emission-reduction factors. EERs are ratios of the fuel economy of alternative vehicles to petroleum-based vehicles that are used to account for differences in energy efficiencies of the alternative fuel vehicle in GHG

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20 Energy Commission. 2013. Personal communication, October 1, 2013.

21 For typical definitions of alternative fuel types, including Fischer-Tropsch fuels, see the Alternative Fuels Data Center, available at: www.afdc.energy.gov/fuels/emerging_xtl_fuels.html

22 ARB. 2012. *Final Regulation Order*. Table 5. EER Values for Fuels Used in Light- and Medium-Duty, and Heavy-Duty Applications. Sacramento. 107 pp. www.arb.ca.gov/fuels/lcfs/CleanFinalRegOrder112612.pdf..

emission factors, and are codified within the LCFS framework. Following application of EERs, the difference between the replaced petroleum fuel blends (gasoline or diesel) used for transportation and the alternative fuels is calculated and applied to the matching group of projects using those fuel pathways. For example, all fuel production infrastructure projects using "used cooking oil" (UCO) are matched to the GHG emission reduction factor generated from the UCO to biodiesel pathway that would replace petroleum-based diesel. Soybean and corn based biofuel pathways include land-use change (LUC) estimates in total GHG emissions, as taken from the LCFS framework.[23]

Table 8: Descriptions and Estimates of GHG Emission Factors

Fuel	Fuel System Description	GHG Emission Estimate (g CO_2eq/MJ)	Source
Gasoline	AVG California gasoline blend	99	(A)
Diesel	AVG California diesel	98	(A)
Biodiesel	Midwest soybean transesterification (see source notes below)	83	(A)
Biodiesel	algae oil transesterification	54	(C)
Biodiesel	corn oil transesterification	4	(A)
Biodiesel	rapeseed transesterification	39	(C)
Biodiesel	used cooking oil (UCO) transesterification, where "cooking" is required	16	(A)
Biodiesel	tallow transesterification	10	(B)
Biodiesel	90% UCO, 10% soy	23	(A)
Biodiesel	50% soy, 40% corn, 10% UCO	45	(A)
Biodiesel	80% tallow, 20% UCO	11	(A, B)
Biodiesel	80% UCO, 10% algae, 10% rapeseed	22	(A, C)
CNG	California NG via pipeline; compressed in CA	68	(A)
CNG	landfill gas cleaned up to pipeline quality NG; compressed in CA	11	(A)
CNG	dairy digester biogas to CNG	13	(A)
CNG	90% NG, 10% Dairy Gas	62	(A)
CNG	75% NG, 25% Dairy Gas	54	(A)
CNG	50% dairy waste, 50% wood waste	18	(A, E)
CNG	wood waste anaerobic digestion	23	(E)
CNG	wastewater treatment AD w/CCS	-178	(D)
LNG	North American NG delivered via pipeline; liquefied in CA using liquefaction with 90% efficiency	72	(A)

23 ARB. 2012. *Final Regulation Order.* Table 5. EER Values for Fuels Used in Light- and Medium-Duty, and Heavy-Duty Applications. Sacramento. 107 pp. www.arb.ca.gov/fuels/lcfs/CleanFinalRegOrder112612.pdf.

LNG	dairy digester biogas to LNG liquefied in CA using liquefaction with 90% efficiency	18	(A)
LNG	70% LNG, 30% Dairy Biogas	56	(A)
LPG	AVG CA LPG	81	(B)
Electric	CA marginal	105	(A)
Ethanol	California average; 80% Midwest Average; 20% California; Dry Mill; Wet DGS; NG	96	(A)
Ethanol	forest residues	14	(B)
Ethanol	corn stover	11	(B)
Ethanol	Brazilian sugarcane with average production process and electricity co-product credit	20	(A)
Ethanol	Sugarbeets	35	(E)
Ethanol	90% corn stover, 10% wood waste	35	(B)
Ethanol	80% sugarbeets, 20% forest residues	31	(B, E)
FT Diesel	MSW FT diesel	26	(E)
Hydrogen	liquid H2 from central reforming of NG	133	(A)
Hydrogen	compressed H2 from on-site reforming with renewable feedstocks	76	(A)
Hydrogen	66% NG, 33% renewable	114	(A)
Hydrogen	23% NG, 77% renewable	89	(A)
RD	UCO or tallow hydroprocessing	20	(A)
RD	dairy waste pyrolysis	20	(D)

NOTES:
The process of transesterification is described here: www.afdc.energy.gov/fuels/biodiesel_production.html
A. ARB. 2012. *Final Regulation Order*. Table 6. Carbon Intensity Lookup Table for Gasoline and Fuels that Substitute for Gasoline. Sacramento. 107pp. Available at: www.arb.ca.gov/fuels/lcfs/CleanFinalRegOrder112612.pdf
B. ARB. 2011. CA-GREET. Version 1.8b. www.arb.ca.gov/fuels/lcfs/lcfs.htm
C. ANL. GREET. Version 2012r2.
D. ANL. GREET. Version 2012r2. Modified pathways.
E. S&T[2] Consultant. GHGenius. Modification for the Transportation Energy Futures project.

Air pollutant emission reduction factors, in units of grams per mile driven, are applied to the VMT estimates associated with fuel displacement calculations. However, unlike the GHG carbon intensity factors, air pollutant emission factors are more limited in the scope of applicable vehicles and fuels, as indicated in Table 9. The emission factors are also only tailpipe or vehicle operation emissions, not life-cycle emission across the fuel supply chain. Emission factor values were taken from ARB Emission Factor tables, published for use in evaluating Carl Moyer projects (March 2013, see notes for Table 9). The top section of Table 9 reviews tailpipe emission standards for baseline, ULEV, and SULEV vehicles. The resulting reductions or displacement amount for substitution cleaner vehicles are indicated in the bottom of the table.

Table 9: Nominal Tailpipe Emissions Used to Estimates Air Pollutant Reduction Benefits

New or Displaced Vehicle Type	Standard / Displacement	ROG	NOx	PM2.5 (Exhaust)	PM2.5 (Total)
Standards					
New LDV (<=8500 lbs)	Baseline	205	775	9	49
	ULEV	55	70	9	49
	SULEV	10	20	9	49
New LDV (8501-10,000 lbs)	Baseline	242	875	86	144
	ULEV	143	200	54	112
	SULEV	100	100	54	112
New MDV (10,001-14,000 lbs)	Baseline	316	1292	86	150
	ULEV	167	400	54	117
	SULEV	117	200	54	117
New LDV or MDV (all weights)	ZEV	0	0	0	40
Displacements					
Displaced LDV (<=8500 lbs)	ULEV disp. By SULEV	45	50	0	0
	ULEV disp. By ZEV	55	70	9	9
Displaced LDV (8501-10,000 lbs)	ULEV disp. By SULEV	43	100	0	0
	ULEV disp. By ZEV	143	200	54	72
Displaced MDV (10,001-14,000 lbs)	ULEV disp. By SULEV	50	200	0	0

NOTES: Baseline is 60% LEV, 40% ULEV; SULEV is for 120,00 mile durability, and same emissions for PZEV and AT-PZEV with 150,000 mile durability.
Source: Methods to Find the Cost-Effectiveness of Funding Air Quality Projects, Emission Factor Tables, ARB, May 2013, available at: http://www.arb.ca.gov/planning/tsaq/eval/evaltables.pdf

2.1.4 Scenarios

The target year for the 2013 benefit analysis is 2025. To that end, the years 2011-2025 were evaluated for this benefit analysis, with 2025 being consistently reported in all results of this 2013 benefits analysis.

Multiple scenarios for the estimation of expected program benefits are not evaluated. Since only expected program benefits are being analyzed in this section, no high or low scenarios representing alternative market growth and transformation benefit scenarios are represented. These benefits are explored in subsequent sections.

The lack of scenarios does not imply that there is absolute certainty in the data used for the estimation of expected program benefits. There are several sources of uncertainty introduced through the use of approximations for some data (for example, sugarcane GHG emissions for sweet sorghum), the resolution of data (for example, air pollutants reported at the vehicle class level rather than vehicle make), and the use of static value where reality is more dynamic (for example the use ARB energy economy ratio [EER] values). However, more refined data in these areas would introduce minor changes relative to the absolute magnitude of benefits calculated.

2.2 Electric Drive Vehicles, Manufacturing, and Infrastructure

Figure 5 shows expected program petroleum-use reduction benefits from ARFVTP funding. By 2025, electric vehicle (EV) manufacturing projects are estimated to achieve the greatest petroleum use reductions of about 140 million gasoline gallon equivalent (GGE) per year. Electric chargers are estimated to achieve petroleum reductions of about 8 million GGE per year. At the peak in about 2017, the light-duty BEVs and PHEVs and the electric commercial truck projects are each estimated to achieve 0.4 million GGE per year, with truck benefits dropping off more quickly as total VMT decline more rapidly than for the LDVs.

The following are key assumptions underlying these expected benefit calculations:

- Manufacturing benefits are estimated to achieve the greatest petroleum-use reductions because new vehicles are produced each year that are expected to replace petroleum vehicles. This continued production of new vehicles year after year represents significant leveraging of ARFVTP funds.
- Electric chargers have a more lasting petroleum reduction benefit than vehicles because of the longer turnover time of the infrastructure relative to EVs. Electric chargers (and all other infrastructure) are assumed to have a turnover beyond the program benefits assessment period (that is, 2011-2025).

Without sufficient market demand for vehicles, the high and persistent manufacturing levels are potentially unfeasible. Therefore, the vehicle incentives and electric chargers are still important even if the relative expected benefits are low by comparison. Moreover, the combined influence of each project type on PEV markets should reinforce positive growth.[24] Chapter 3 addresses the market transformation benefits of PEV incentives and EVSE infrastructure.

Figure 6 shows expected program GHG emission reduction benefits from ARFVTP electric-drive projects. GHG emission reductions are directly related to reductions in petroleum use. All projects using electricity assume the use of California marginal grid electricity as throughput. Therefore, there are no significant differences between GHG emission reductions per unit of petroleum fuel use reduced between projects.

24 There could be an argument that the combined influence of these incentives is subadditive. That is, some deployments or electricity use could be realized due to support provided by more than one project, rather than each project resulting in mutually exclusive and additive benefits. Additional research is needed in this area to better understand the combined influence and interaction among multiple support mechanisms.

Figure 5: Estimated Electric Drive Project Petroleum Reductions in Million GGEs

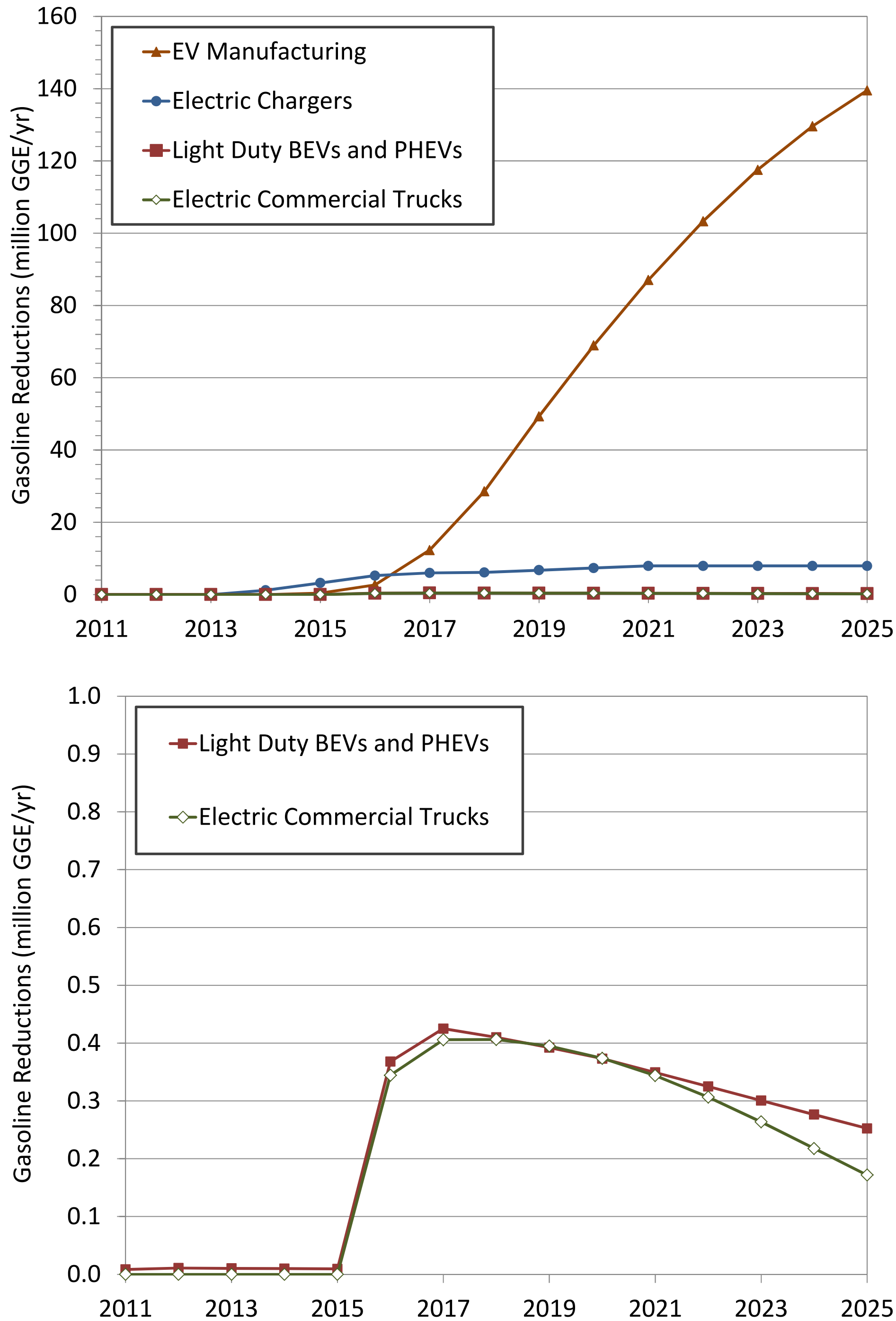


Figure 6: Estimated Electric Drive Project GHG Emission Reductions

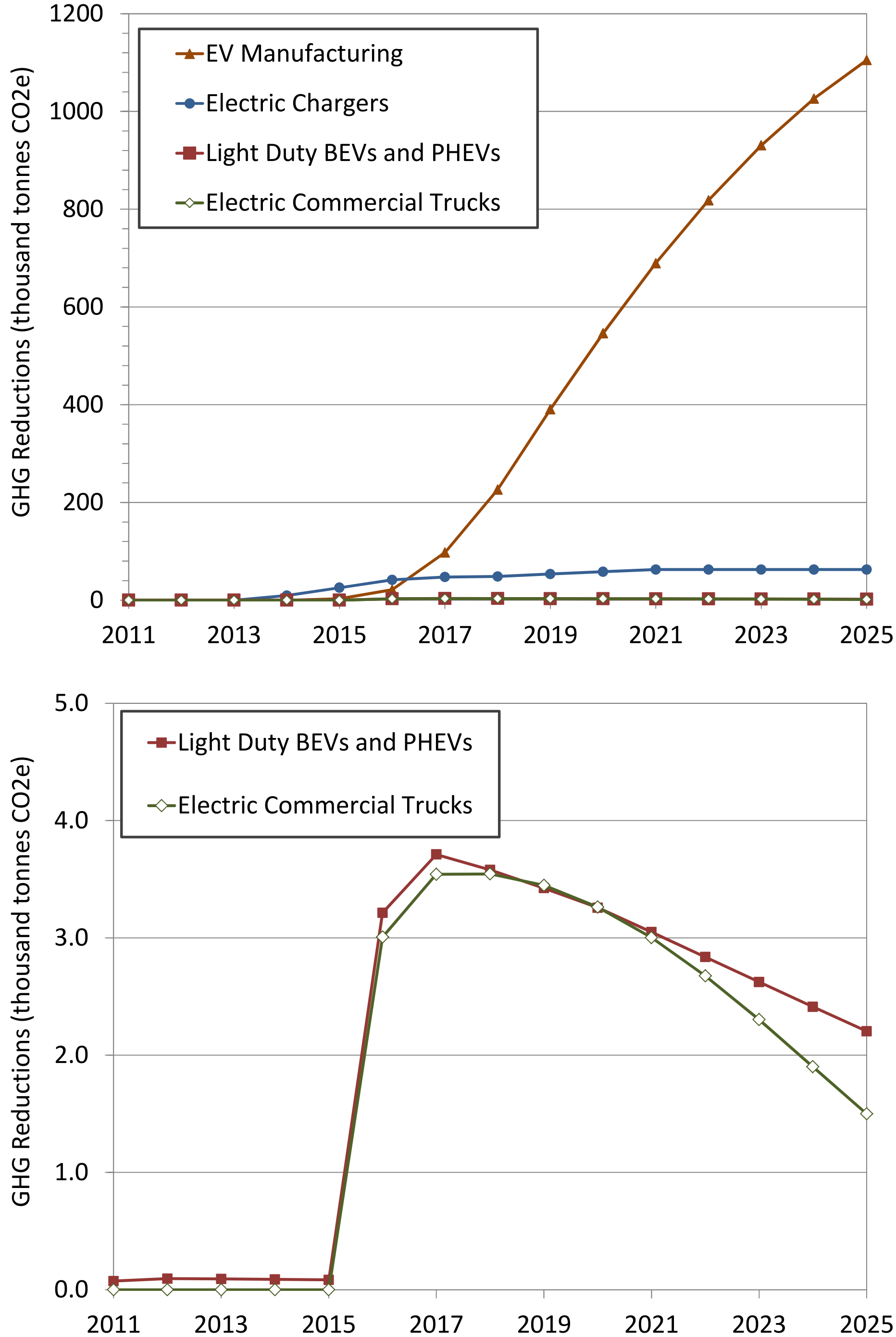
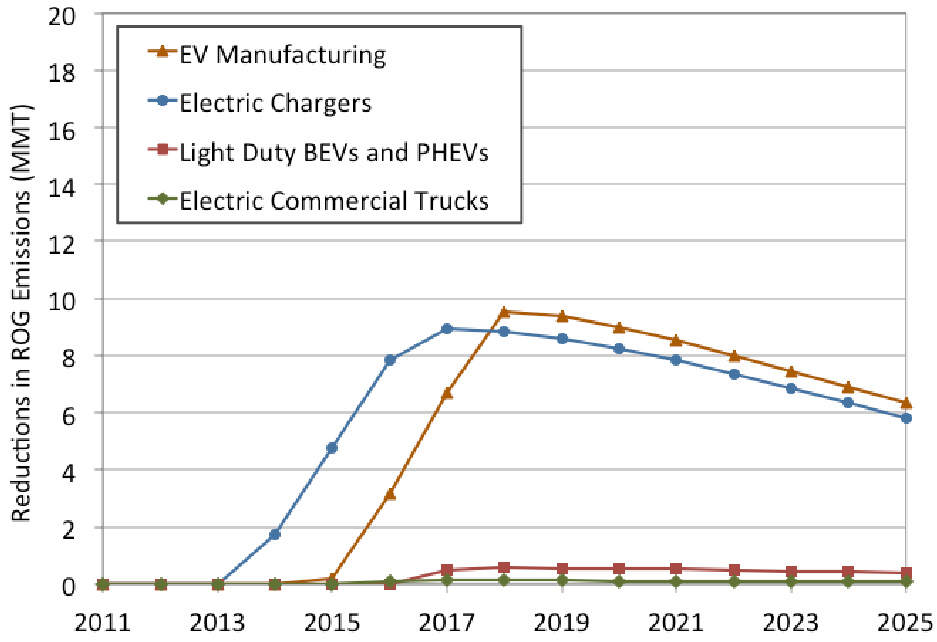


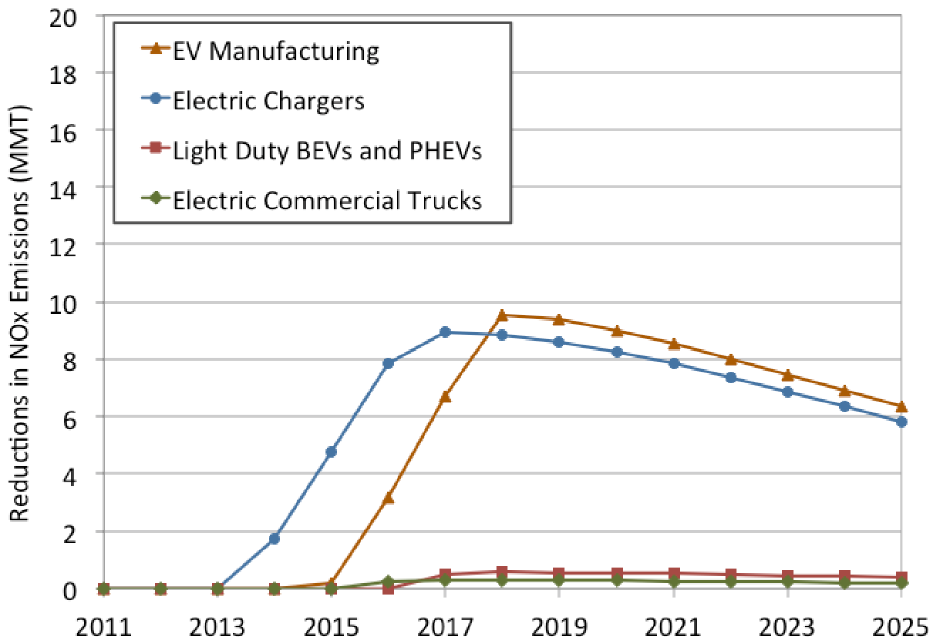
Figure 7 shows expected program air pollutant emission reduction benefits from the ARFVTP electric drive projects. Similar to GHG emissions, air pollutant emission factors are consistently applied across electric drive projects, but on a per mile basis rather than a fuel-energy basis. Appendix C contains additional details on criteria emission results for expected benefits.

Figure 7: Estimated Electric Drive Air Pollutant Emission Reductions

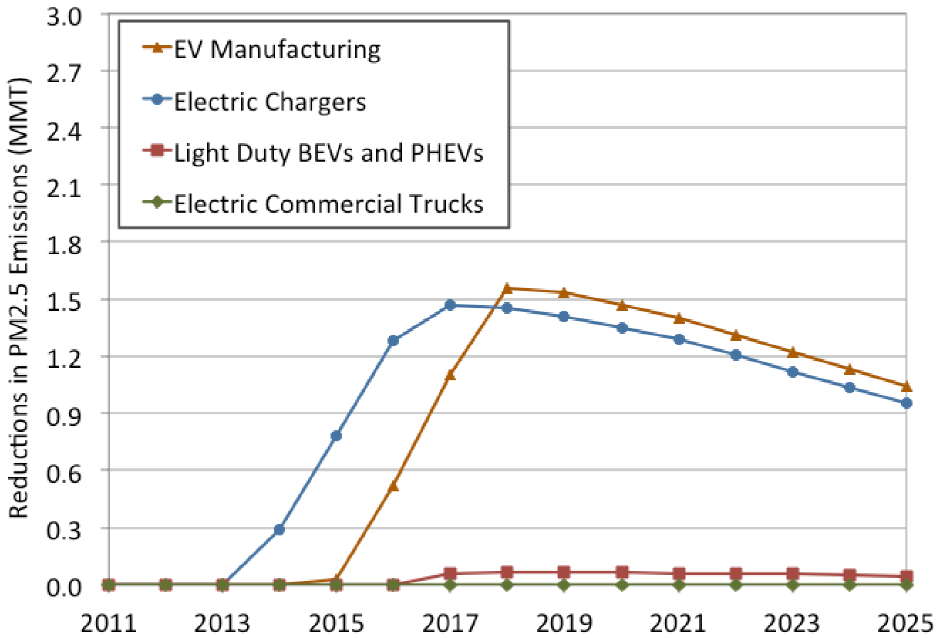
(a) ROG



(b) NOx



(c) $PM_{2.5}$



2.3 Gaseous Fuel Vehicles and Infrastructure

Figure 8 shows expected program petroleum reduction benefits from ARFVTP funding for gaseous fuel vehicles. By 2025, natural and renewable gas delivery projects are estimated to achieve the greatest annual petroleum reductions of about 40 million diesel gallon equivalent (DGE). Biomethane projects are estimated to achieve annual reductions of about 3.7 million DGE by 2025. At the peak in about 2014, the NG and LPG commercial trucks projects are estimated to achieve annual reductions of 20 million and 1.2 million DGE, respectively.

Natural and renewable gas delivery projects are estimated to achieve the most petroleum use reductions because of high fuel throughput. Natural gas and renewable gas fueling infrastructure is estimated to have a more lasting petroleum reduction benefit than vehicles because of the longer turnover time of the infrastructure relative to EVs. Similar trends can be seen for biomethane fuel production.

Figure 9 compares estimates of GHG emission reductions from gas-related projects. Biomethane projects show relatively large GHG emission reductions through a combination of high petroleum reductions and very low GHG emission factors.

Some of the lowest GHG emission factors used in this report are for biomethane projects. Biomethane projects frequently use waste feedstocks (for example, wastewater treatment waste, food waste, and dairy waste) that if not used for biofuel would otherwise be emitting the GHG methane. The use of these feedstocks avoids these methane emissions and is given credit for this in the GREET models. Avoidance of methane emissions as a consequential benefit is included based on GREET methodology, but an argument for exclusion could be made.

Gas and renewable gas fueling infrastructures are estimated to achieve GHG emission reductions through a combination of the largest petroleum reduction and some projects expecting throughput of partial or full renewable biomethane. Gaseous fuel vehicles have relatively low long-term GHG emission reductions compared to fuel supply systems, due to retirement and declining use of vehicles compared to supply infrastructure.

2.4 Hydrogen Infrastructure

Figure 10 shows that by 2025, ARFVTP's hydrogen refueling infrastructure projects are estimated to achieve petroleum use reductions of about 3.3 million GGE per year. Figure 11 shows the estimated GHG emission reductions achieved through reducing petroleum use and providing LDV miles through more efficient FCEVs running on hydrogen produced, primarily, from natural gas. Figure 12 shows the estimated air pollutant emission reductions achieved per year. Each emission factor is proportional to the FCEV miles driven over time, and, therefore, air pollutant reductions decline as the fleet of FCEVs utilizing the refueling stations ages over time.

Figure 8: Estimated Gaseous Fuel Vehicle and Infrastructure Petroleum Fuel Reductions

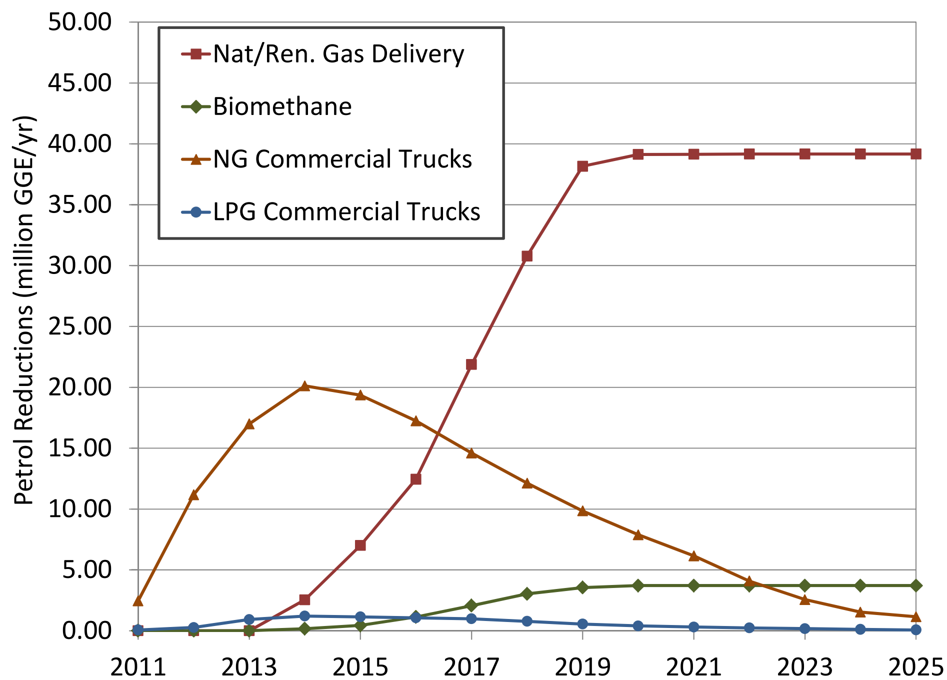


Figure 9: Estimated Gas-Related Annual GHG Emission Reductions

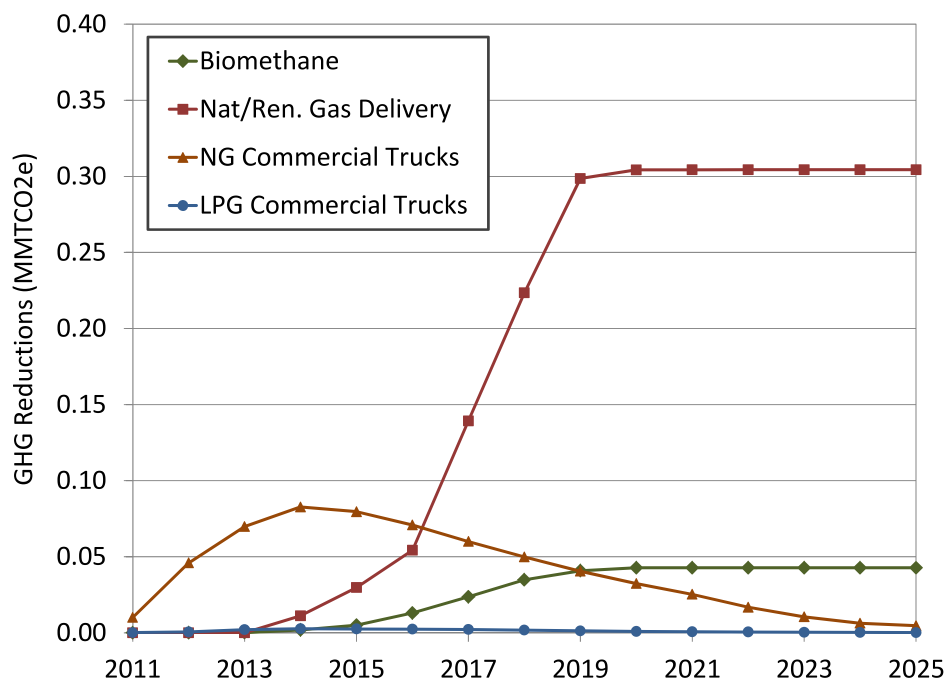


Figure 10: Estimated Hydrogen-Related Annual Petroleum Reductions

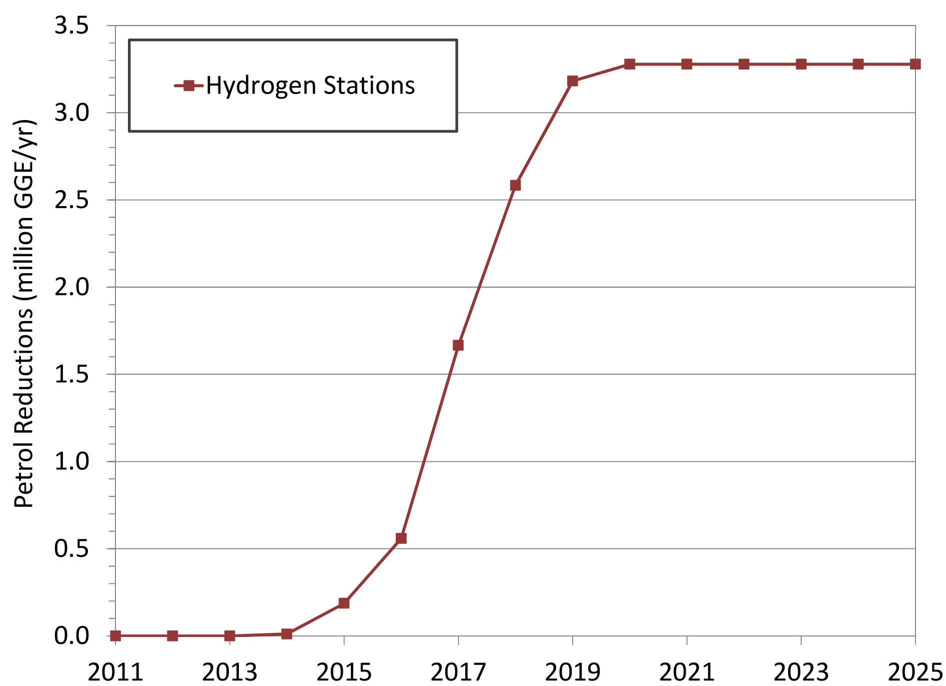


Figure 11: Estimated Hydrogen-Related Annual GHG Emission Reductions

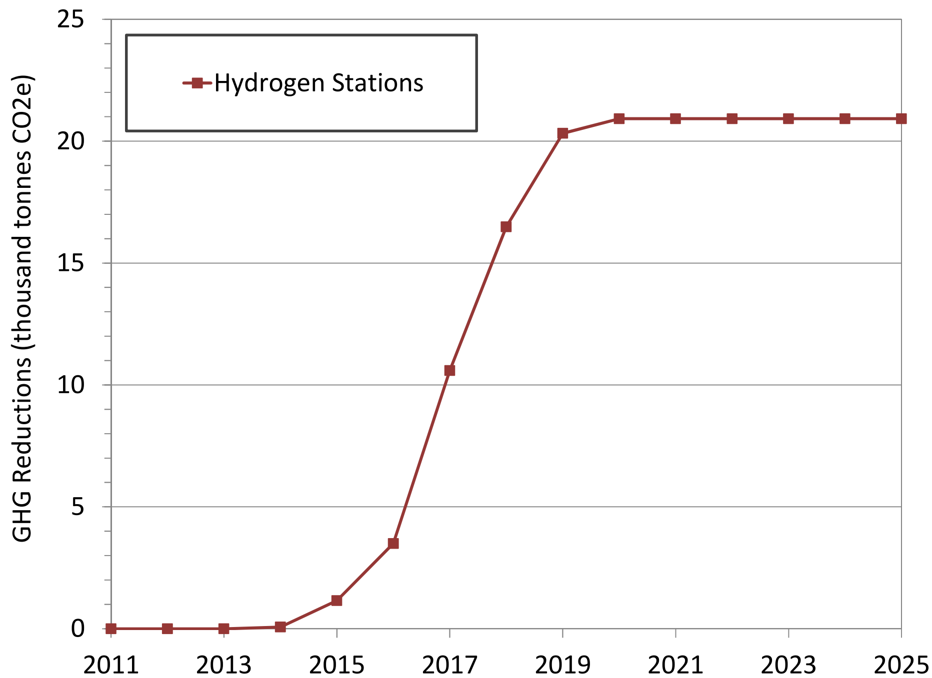
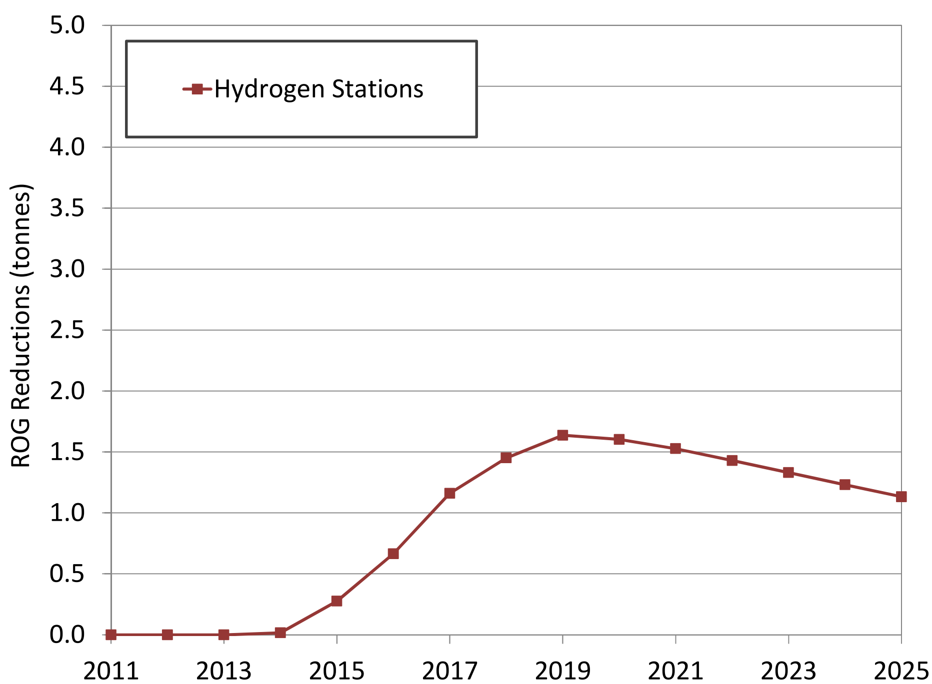
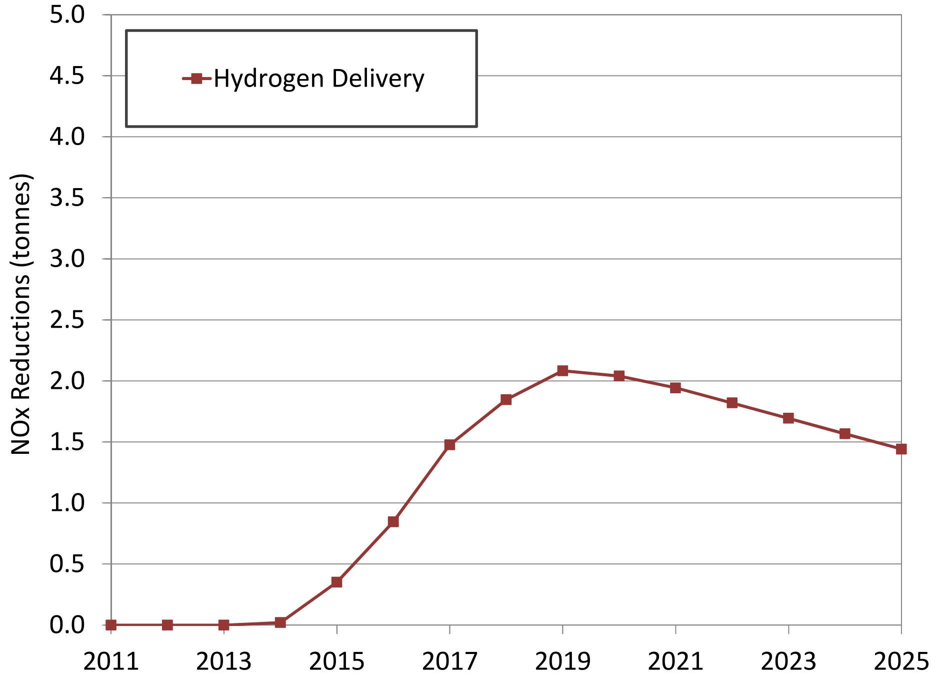


Figure 12: Estimated Hydrogen-Related Annual Air Pollutant Emission Reductions

(a) ROG

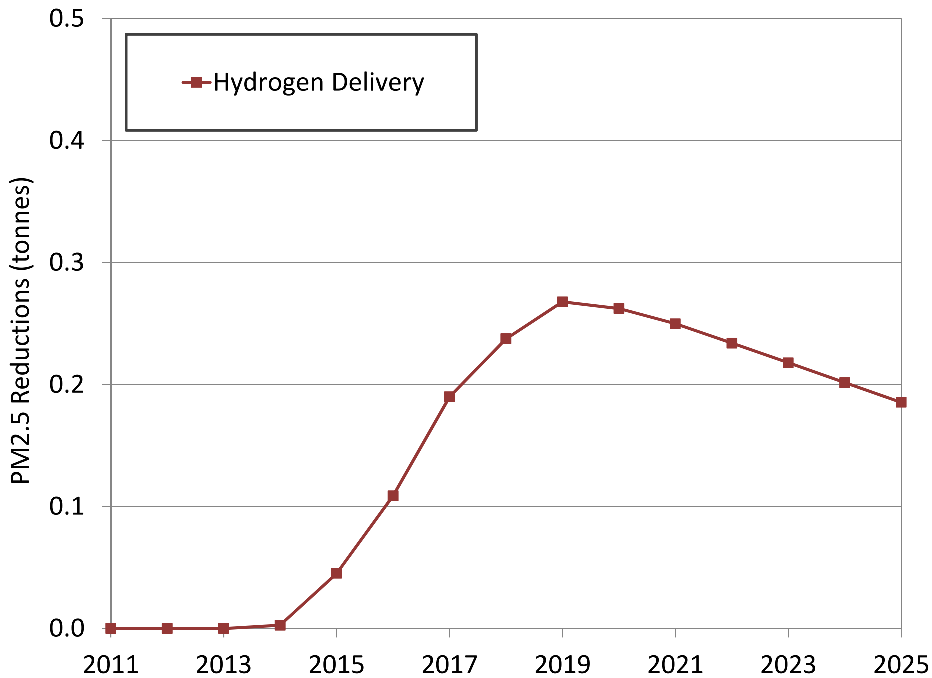


(b) NO_X



Hydrogen Delivery
NOx Reductions (tonnes)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
2011
2013
2015
2017
2019
2021
2023
2025

(c) $PM_{2.5}$



Hydrogen Delivery
PM2.5 Reductions (tonnes)
0.5
0.4
0.3
0.2
0.1
0.0
2011
2013
2015
2017
2019
2021
2023
2025

2.5 Advanced Fuel Production and Supply Infrastructure

Figure 13 compares estimated petroleum-use reductions achieved by funding diesel and gasoline substitute-related projects. By 2025, petroleum-use reductions from diesel substitute fuel production, gasoline substitute fuel production, biodiesel fueling infrastructure, and E85 ethanol fueling infrastructure are estimated to achieve about 27 million, 10 million, 8.5 million, and 27 million DGE or GGE per year, respectively.

Figure 14 compares the estimated GHG emission reductions achieved through ARFVTP investments in advanced fuel production and supply infrastructure. An important driver of GHG emissions for biofuels considered here is land-use change (LUC). LUC was included in alignment with LCFS GHG emission tables. The effect of LUC is seen by looking at achievable GHG emission reductions for projects producing or facilitating the use of some biofuels (for example, corn and soybeans). GHG emission reductions for some project categories such as E85 ethanol and biodiesel would be much higher without LUC.

2.6 Summary of Expected Benefits

The increased deployment of alternative low-carbon fuels and vehicles could improve air quality by reducing some tailpipe air pollutant emissions, address climate change by reducing GHG emissions, and reduce dependence on petroleum. Alternative fuels and vehicles can play a role in helping reach ARB's zero-emissions vehicle (ZEV) regulation mandate and California's GHG and petroleum reduction goals.

Of the projects analyzed for expected benefits, ARFVTP has invested $112 million (17 projects) in vehicles, $158 million (132 projects) in refueling infrastructure, and $81 million (29 projects) on fuel production infrastructure. Figure 15 shows total petroleum use reductions across these major project categories. Annual petroleum-use reductions by 2025 included 109 million gallons per year from vehicle projects, 86 million gallons per year from refueling infrastructure, and about 30 million gallons from fuel production projects. In sum, petroleum fuel reductions for all three expected benefit categories approach 225 million gallons by 2025.

Figure 16 shows estimated total GHG emission reductions across broad project categories. The GHG emission reductions are comparable among the three categories by 2025, ranging from 0.3 to 0.9 MMTCO$_2$e. The steady growth in GHG reductions in the vehicle category is due largely to electric drive vehicle production and manufacturing projects. In comparing petroleum fuel reductions and GHG reductions, the refueling infrastructure makes a larger relative contribution to petroleum-fuel reductions than GHG reductions. This is due largely to ethanol and natural gas refueling stations displacing large volumes of petroleum fuel, but having a relatively high fuel carbon intensity compared to fuels used in other projects.

The annual trends by subcategory are indicated Tables 10 and 11, and the results are shown by category in Figures 17 and 18 along with pie charts to indicate the relative contribution of subcategories to cumulative reductions over the entire analysis time frame (2011-2025).

Figure 13: Estimated Diesel and Gasoline Substitute-Related Annual Petroleum Reductions in DGE or GGE

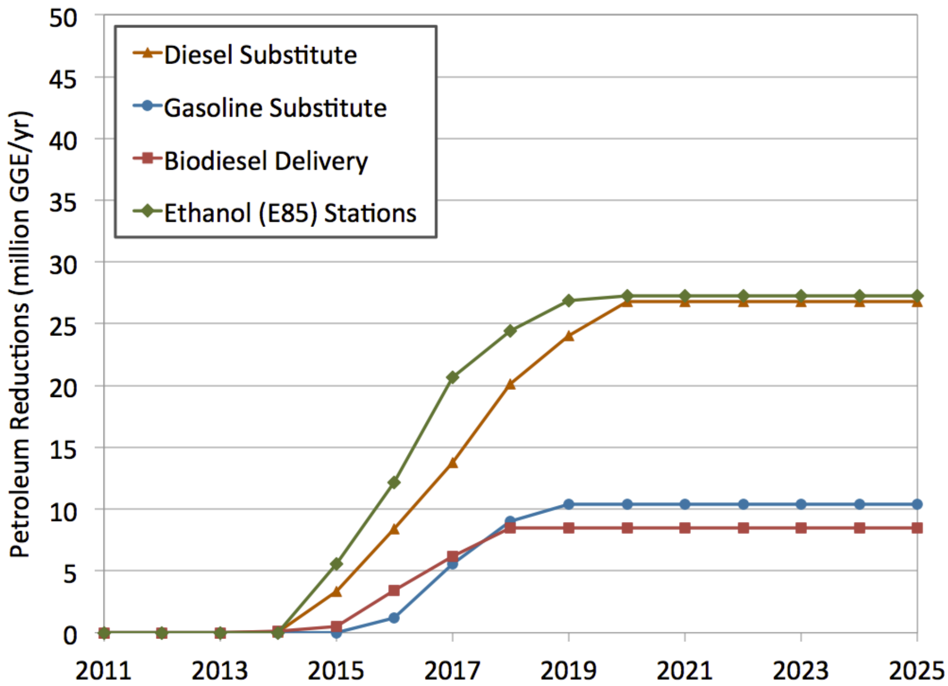


Figure 14: Estimated Diesel and Gasoline Substitute-Related Annual GHG Emission Reductions

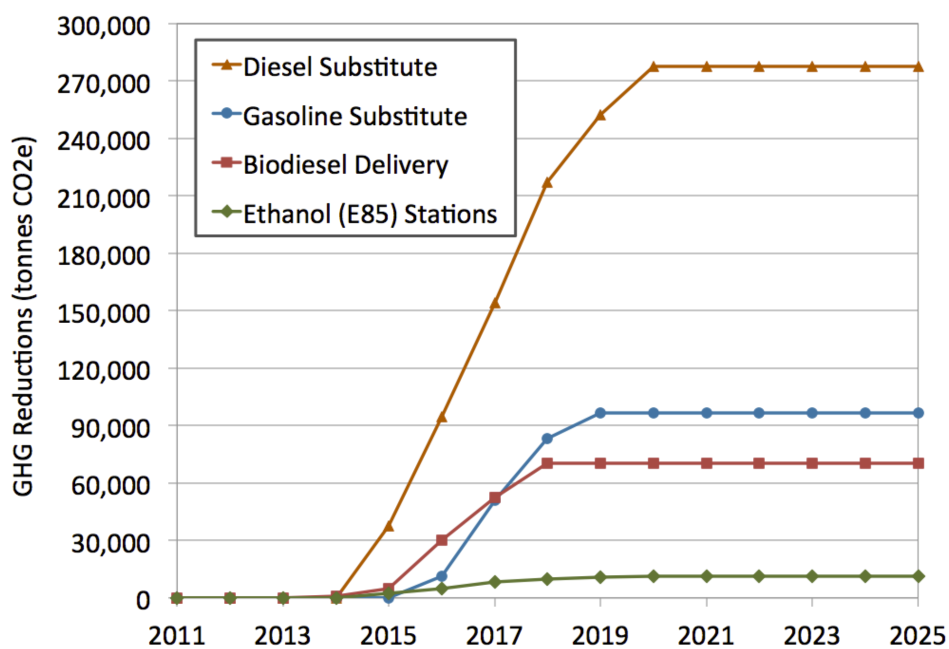


Figure 15: Estimated Benefit Petroleum Fuel Reductions

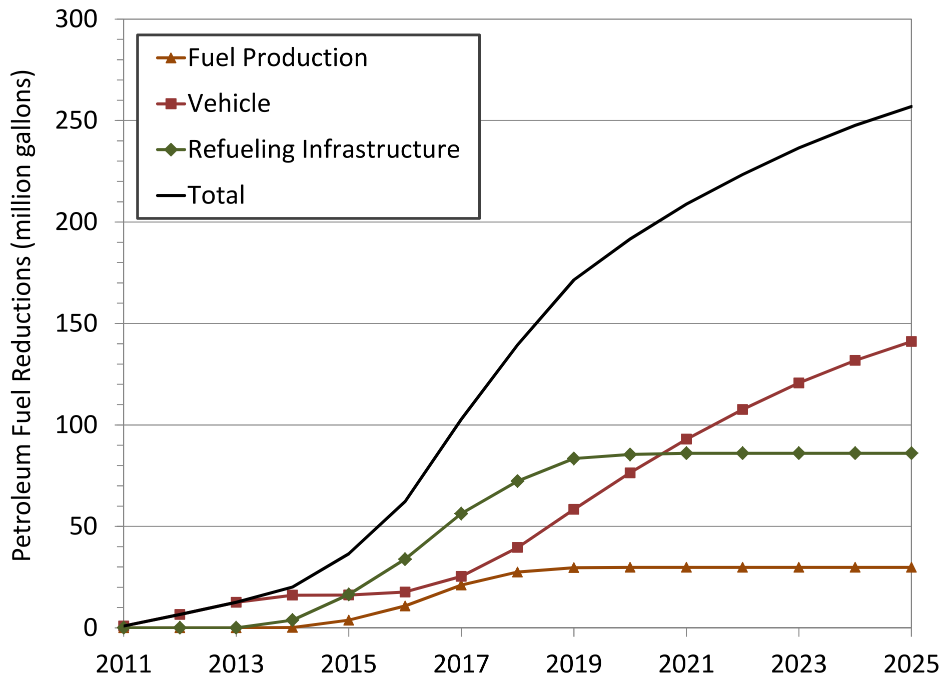


Figure 16: Estimated Total Annual GHG Emission Reductions per Year

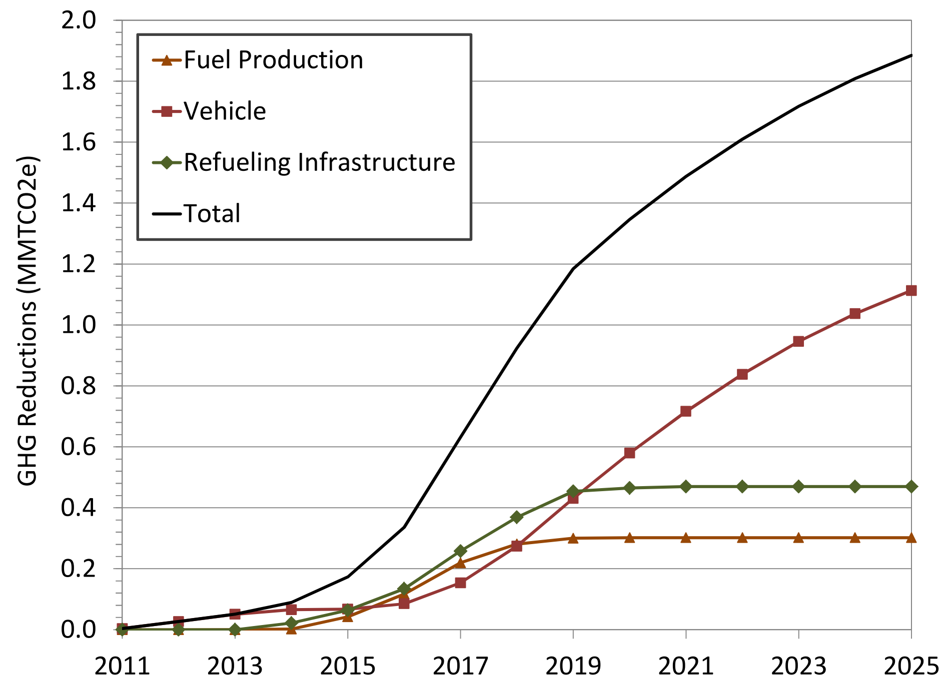


Table 10: Summary of Expected GHG Reduction Benefits

Expected Benefits: GHG Reductions (thousand tonnes CO2e)		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Fueling Infrastructure	Biodiesel	0.0	1.0	5.0	30.0	52.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5
	Natural and Renewable Gas	0.0	11.2	29.7	54.3	139.3	223.5	298.6	304.3	304.3	304.4	304.4	304.4	304.4
	Electric Chargers	0.0	9.4	25.4	41.5	47.4	48.4	53.4	58.1	62.7	62.7	62.7	62.7	62.7
	E85 Ethanol	-	0.0	2.3	5.0	8.4	9.9	11.0	11.1	11.1	11.1	11.1	11.1	11.1
	Hydrogen	-	0.1	1.2	3.5	10.6	16.5	20.3	20.9	20.9	20.9	20.9	20.9	20.9
Vehicle	Light-Duty BEVs and PHEVs	0.1	0.1	0.1	2.9	3.4	3.2	3.1	3.0	2.8	2.6	2.4	2.2	2.0
	Electric Commercial Trucks	-	-	-	2.7	3.2	3.2	3.1	3.0	2.7	2.4	2.1	1.7	1.4
	Gas Commercial Trucks	71.8	85.3	82.0	73.2	62.2	51.6	41.7	33.3	26.0	17.3	10.9	6.5	4.8
	Manufacturing	-	0.0	2.0	18.7	79.4	180.0	304.6	422.4	531.1	629.2	715.6	789.5	851.2
Fueling Production	Biomethane	-	-	1.6	9.1	21.6	34.2	40.8	42.7	42.7	42.7	42.7	42.7	42.7
	Diesel Substitute	-	0.1	37.5	94.5	154.2	216.9	252.3	277.5	277.5	277.5	277.5	277.5	277.5
	Gasoline Substitute	-	-	-	11.2	51.1	83.3	96.5	96.5	96.5	96.5	96.5	96.5	96.5
Total		71.9	107.1	186.8	346.5	633.2	941.2	1,195	1,343	1,448	1,537	1,617	1,686	1,745

Table 11: Summary of Expected Petroleum Reduction Benefits

Expected Petroleum Reduction Benefits (million GGE/DGE)		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Fueling Infrastructure	Biodiesel	0.0	0.1	0.5	3.4	6.2	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5
	Natural and Renewable Gas	0.0	2.5	7.0	12.4	21.9	30.8	38.2	39.1	39.2	39.2	39.2	39.2	39.2
	Electric Chargers	0.0	1.2	3.2	5.2	6.0	6.1	6.7	7.3	7.9	7.9	7.9	7.9	7.9
	E85 Ethanol	-	0.0	5.6	12.1	20.6	24.4	26.9	27.2	27.2	27.2	27.2	27.2	27.2
	Hydrogen	-	0.0	0.2	0.6	1.7	2.6	3.2	3.3	3.3	3.3	3.3	3.3	3.3
Vehicle	Light-Duty BEVs and PHEVs	0.0	0.0	0.0	0.4	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.3	0.3
	Electric Commercial Trucks	-	-	-	0.3	0.4	0.4	0.4	0.4	0.3	0.3	0.3	0.2	0.2
	Gas Commercial Trucks	17.9	21.3	20.5	18.3	15.6	12.9	10.4	8.3	6.5	4.3	2.7	1.6	1.2
	Manufacturing	-	0.0	0.2	2.4	10.0	22.7	38.5	53.3	67.1	79.5	90.3	99.7	107.5
Fueling Production	Biomethane	-	-	0.1	0.8	1.9	3.0	3.5	3.7	3.7	3.7	3.7	3.7	3.7
	Diesel Substitute	-	0.0	3.4	8.4	13.7	20.1	24.0	26.8	26.8	26.8	26.8	26.8	26.8
	Gasoline Substitute	-	-	-	1.2	5.5	9.0	10.4	10.4	10.4	10.4	10.4	10.4	10.4
Total		17.9	25.1	40.7	65.6	103.9	140.9	171.1	188.8	201.2	211.4	220.7	228.8	236.1

Figure 17: Summary of GHG Reductions From Expected Benefits

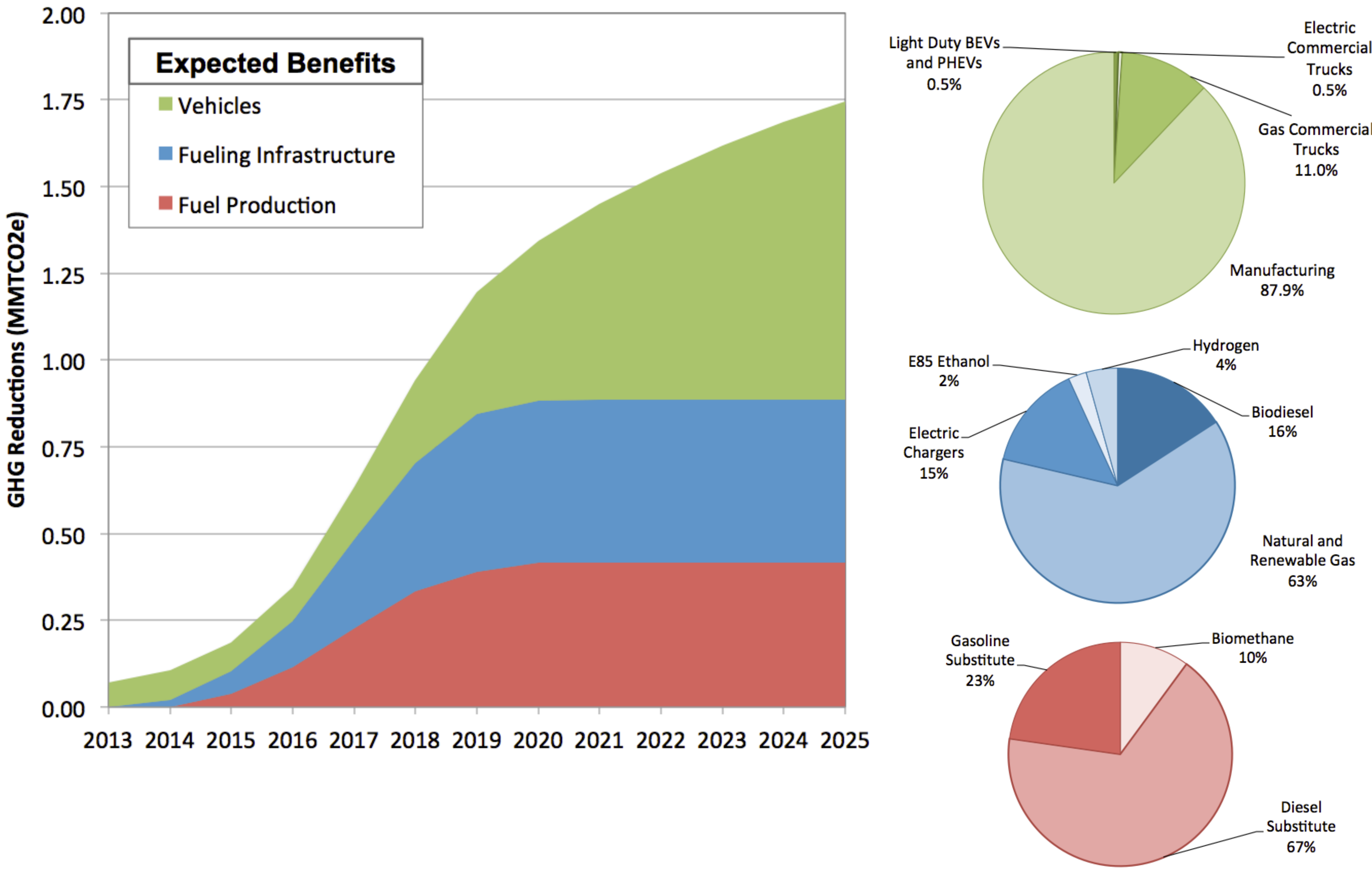
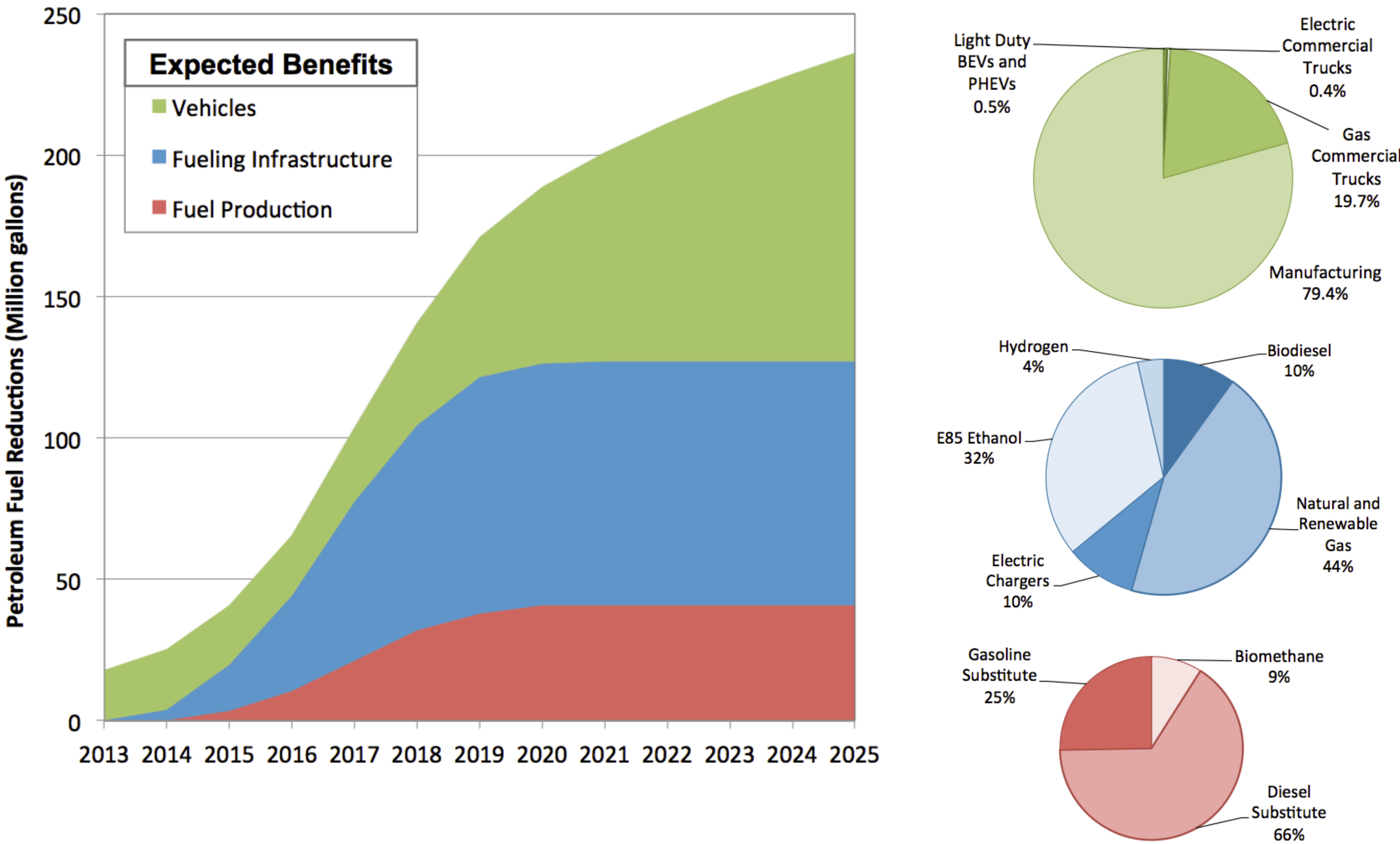


Figure 18: Summary of Petrol Fuel Reductions From Expected Benefits



CHAPTER 3: Market Transformation Benefits

Market transformation benefits are based upon more uncertain data and more hypothetical estimation methods than the expected benefits discussed in the previous chapter. These benefits are associated with effects that ARFVTP activities have on factors influencing current and future market conditions for new technologies. Some of these benefits may be "second order" benefits that follow from successful deployment of technologies accounted for under expected benefits. For example, demonstrating a small-scale biofuel production process would result in a small volume of low-carbon fuel (expected benefit), while the success of that demonstration project may increase the likelihood that the technology will be deployed at a larger scale (market transformation benefit). In addition, results from a successful demonstration may provide the company with performance data to attract new private or public funding. In this case the direct outcome of the project itself may be limited, but the proven track record improves the market viability of the next generation of the same (or similar) technology. Some market transformation benefits are distinct from the corresponding expected benefits. For example, installing hydrogen stations provides the direct benefit of efficient fuel cell electric vehicles (FCEVs) driving on hydrogen fuel and displacing gasoline use (expected benefit), while an increase in the geographic availability and convenience of additional stations will influence future consumer purchase decisions, and therefore the future market conditions for FCEV adoption (market transformation benefit). These examples indicate how market transformation benefits are more uncertain and theoretical than expected benefits.

Though there are many types of potential market transformation influences associated with ARFVTP activities, this section quantifies three types, each including multiple subcategories. The term "influence" is used here to refer to the functional mechanism through which a project or set of projects might change future market adoption rates. The resulting market transformation benefits accrue due to the resulting increase in market share. The three influences are:

1. **Vehicle price reductions.**
    a. Reduction in the perceived price of PEVs due to increased availability of public EVSE stations.
    b. Reduction in the perceived price of FCEVs due to increased availability of hydrogen stations.
    c. Reduction in the price of PEVs due to Clean Vehicle Rebate Program (CVRP) rebates.
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 ARFVTP support for the current generation of the same (or similar) technology.

The method relied upon to estimate benefits associated with vehicle price reductions is based upon assumptions about consumer behavior and a demand elasticity calculation framework. Benefits due to vehicle and fuel component cost reductions are determined using an industry experience curve framework in which costs decline with increased cumulative output. Benefits associated with next-generation technologies are based upon project-specific data for fuel production processes and truck demonstrations supported by ARFVTP. Each approach to estimating market transformation benefits is discussed in more detail in the methods section below. The ARFVTP project categories where each of these approaches is applied are summarized in Table 12. As indicated, vehicle price reductions apply to EVSE and hydrogen fueling stations, vehicle production cost reductions apply to a select number of vehicle categories, and next generation benefits are determined for three fuel production categories. The methods used to estimate market transformation benefits are reviewed in the following section. This is followed by a section with assumptions and results for each category fuel or technology category indicated in Table 12.

Table 12: Expected Benefits Type by Project Category

Fuel or Technology Category	Market Transformation Benefits Estimation Methodology		
	Vehicle Price Reduction	Vehicle Cost Reduction	Next Generation
Fueling Infrastructure			
Electric Chargers	X	-	-
Hydrogen Stations	X	-	-
Vehicle			
Light-Duty PEVs (CVRP)	X	-	-
MD-HD ZEV Truck Demonstrations	-	X	-
Electric-Drive components	-	X	-
EV Manufacturing	-	X	-
Electric Commercial Trucks	-	-	X
Fuel Production			
Demonstration Biogas	-	-	X
Demonstration Biodiesel and Renewable Diesel	-	-	X
Demonstration Ethanol	-	-	X

3.1 Methods and Analytic Approach

Among the market transformation categories indicated in Table 12, the methods used to estimate the influence of changes in prices and costs are similar and relatively complicated compared to methods used to estimate expected benefits. Each is estimated using analytic methods that represent market dynamics, consumer behavior, and technology innovation. By comparison, a relatively simple analytic approach is used for the third category of next-generation fuel production and advanced truck demonstrations. Estimating benefits due to vehicle price reductions is challenging because consumers have relatively little experience with many advanced vehicle technologies, and it is unclear to what degree they will value different vehicle attributes. With only very limited empirical data on market outcomes for these vehicles, the research team has only a limited quantitative understanding how different consumer segments might respond to these vehicles when considering the purchase of a new vehicle. An important exception is data available from the Clean Vehicle Rebate Program (CVRP), which is discussed below.

Two types of ARFVTP projects are assessed with respect to market share increases due to vehicle price reductions: (1) increased availability of EVSE and hydrogen stations, and (2) the CVRP. These activities influence consumer decisions to buy a vehicle by reducing the real or perceived purchase price of the vehicle. The benefits associated with a change in price are determined with respect to the estimated price reduction and demand elasticity of consumers within the target market. This is done using a logit market share model, adapted from the LAVE-Trans model, with adjustments to parameters to tailor the model to estimated market conditions in four major urban areas: the Bay Area, Sacramento, Los Angeles, and San Dieog.[25,26]

Reductions in the cost of producing vehicles are achieved through ARFVTP investments in the manufacture of electric-drive components and vehicles, as well as demonstrations of electric-drive components or subsystems. These investments influence production costs by accelerating progress along an aggregate industry experience curve and are estimated as a function of the additional revenue accrued to the electric vehicle production industry from ARFVTP. The corresponding cost reductions occur by shifting the industry down the aggregate or "industrywide" experience curve. Production cost reductions may also be attributed to the vehicle purchase price influence, as pulling more vehicles into the market also moves the industry further down the experience curve. The result would be reduced unit costs for subsequent consumers and an increase in sales in later years, though this second-order effect is

25 For a description of logit market models, see Train, K. E. (2003). *Discrete Choice Methods With Simulation*. Cambridge, Cambridge University Press.

26 For a description of the LAVE-Trans model, see Greene, D., S. Park and C. Liu (2013). "Analyzing the Transition to Electric Drive in California." The Howard H. Jr. Baker Center for Pubic Policy, University of Tennessee, Knoxville, prepared for the International Council on Clean Transportation, White Paper 4.13. http://bakercenter.utk.edu/wp-content/uploads/2013/06/Transition-to-Electric-Drive-2013-report.FINAL_.pdf.

not included in the market transformation benefit estimates.[27] The conditions and economic dynamics under which market transformation investments lead to lower production costs and accelerated market adoption are discussed elsewhere.[28]

This analytic approach assumes that increased industry learning will likely be accompanied by spillover across multiple vehicle electrification components and manufacturing processes. This applies for both plug-in electric and hydrogen vehicles, which share many similar components, such as batteries, power electronics, and thermal management systems. Moreover, this approach assumes that industry is currently at the top of an experience curve, and that increased output, due to either market pull or technology push policies, will result in cost reductions. This assumption seems reasonable given recent developments at the national scale with Corporate Average Fuel Economy (CAFE) regulations and an increasing number of major OEMS announcing new ZEV models and prototypes.[29] In contrast, it is less likely that spillover will occur across distinct fuel production technologies, so the experience curve framework is not relied upon for this technology category.

Estimating cost reductions due to investments in production processes is challenging because, as is often the case for new technologies, the limited number of units deployed often means that experience curves for cost-reduction potential have a limited empirical basis. This may be less true for hybrid electric vehicles, but it is a significant challenge for BEVs and FCEVs. The benefits of investments in electric-drive component technologies are considered through the production cost reduction approach, assuming an aggregate industry experience curve, assuming some spillover across electric-drive platforms is likely.

The analytic approach for next-generation benefits—applied to fuel production and advanced truck demonstrations—does not take into account price influences because consumers are relatively unresponsive to fuel costs. The next-generation approach does not take into account cost reductions through increased industry experience, in part because it is assumed that there is very little spillover across biofuel pathways due to investments in specific processes. It could be argued that investments in electrified trucks could result in spillovers resulting in cost reductions for light-duty ZEVs, but without more granular data at the component level (for example, applicability of specific battery types or thermal management components to multiple vehicle classes), it is difficult to substantiate this claim.

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27 Duke, R., and D. M. Kammen. (1999). "The Economics of Energy Market Transformation Programs." *The Energy Journal,* 20(4): 15–64.

28. See Footnote 27.

29 Lessons from technology innovation systems research case studies suggest that experience curves may be a poor policy framework for forecasting future cost reductions, with increased costs associated with wind turbines being cited as an example (see GEA 2012, Chapter 24). Unit cost increases with increased output are possible for increased ZEV production but seem improbable given the multiple policy factors influencing future ZEV markets and the automotive industry's expertise in reducing costs through economies of scale.

The sections below review the market share approach for vehicle price reductions, the experience curve framework for vehicle production cost reductions, and the next-generation approach for fuel production.

3.1.1 Increased Market Share due to Vehicle Price Reductions

Vehicle purchase price is a major consideration in how consumers choose to buy a vehicle. An analytic approach, based upon discrete choice methods, can be used to quantify the value of other vehicle attributes in terms of an "equivalent vehicle purchase price".[30,31] For example, two vehicles with equal costs and equivalent attributes in all respects would have a 50-50 chance of being purchased by a typical consumer.[32] However, if one of the vehicles has a preferred attribute, such as greater acceleration, or has a retail price $200 lower than the other vehicle, some fraction of consumers will tend to buy the preferred or less expensive vehicle. Discrete choice analysis is an analytic approach to quantifying how consumers value the individual (or discrete) attributes of a product, and can be used to determine, for example, how much additional acceleration might be equivalent to a cost reduction of $200 for the average consumer.

The key variable used to estimate the influence of price on the vehicle purchase decision is the price slope, which is defined as the demand elasticity for the market segment (β) divided by the price point (P) and the inverse of the base market share (s):

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

Assuming that all other vehicle attributes are identical, the change in market share due to a change in perceived or equivalent vehicle price is determined using the following logit function:

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

In this example, assume that P_1 is the price point of a typical incumbent vehicle, and P_2 is the (greater) price of an advanced or alternative fuel vehicle vying for greater market share. If there is a large difference in price between the two vehicles, the market share S_{P2} will be relatively

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30 See footnote 25.

31 Greene, D. (2001). *TAFV Alternative Fuels and Vehicles Choice Model Documentation*. Oak Ridge National Laboratory, http://www-cta.ornl.gov/cta/Publications/TAFV_ChoiceModel1.PDF.

32 In actuality, not all attributes can be defined with precision in an analytic model. Consumer preferences are also uncertain and highly variable. The discrete choice framework allows for a quantification of this variability or uncertainty and captures the degree to which decisions might be made based upon unknown product attributes or consumer preferences. If these unknown factors and uncertainties were not taken into account, and if all other vehicle attributes were assumed equal, with a high degree of precision, 100 percent of consumers would choose the vehicle that cost $1 less than the other vehicle.

small. If the price P_2 of the new LDV is reduced by some amount to a lower price level, P_{2^*}, the resulting change in market share would be the difference between S_{P2^*} and S_{P2}. Because this change in market share applies to a specific market base, price point, and demand elasticity, it can be described as varying with the value of the price slope.

Then the additional sales (ΔQ) from the lower price are calculated as the change in market share times the total base sales of the incumbent vehicle and the advanced vehicle:

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

Three examples of the responsiveness of market share to the components of price slope are indicated in Figure 19. With no difference in vehicle price, and with all other attributes equivalent, there is a 50-50 chance of purchasing either vehicle. [33] This the zero point in the center of the horizontal axis. An increase in the price differential, moving to the right along the horizontal axis, results in lower market share. A negative price differential, with P_2 being lower than P_1, results in greater market share. For a relatively large market base, say 50 percent of the market, and elastic demand (-10), market share changes significantly with a change in vehicle price. A reduction in vehicle price by $5,000 results in a 95 percent probability of purchase, as indicated by the solid black line. As suggested in the equation for price slope above, an increase in the vehicle price or decrease in the base share will result in less responsiveness to price. The example indicated with a relatively high vehicle prices, $40,000, and small base market, 2.5 percent, is similar to the market conditions assumed below for BEVs and FCEVs. Under these relatively inelastic market conditions, a $5,000 reduction in vehicle price results in an increase in market share of only 15 percent (dashed line).

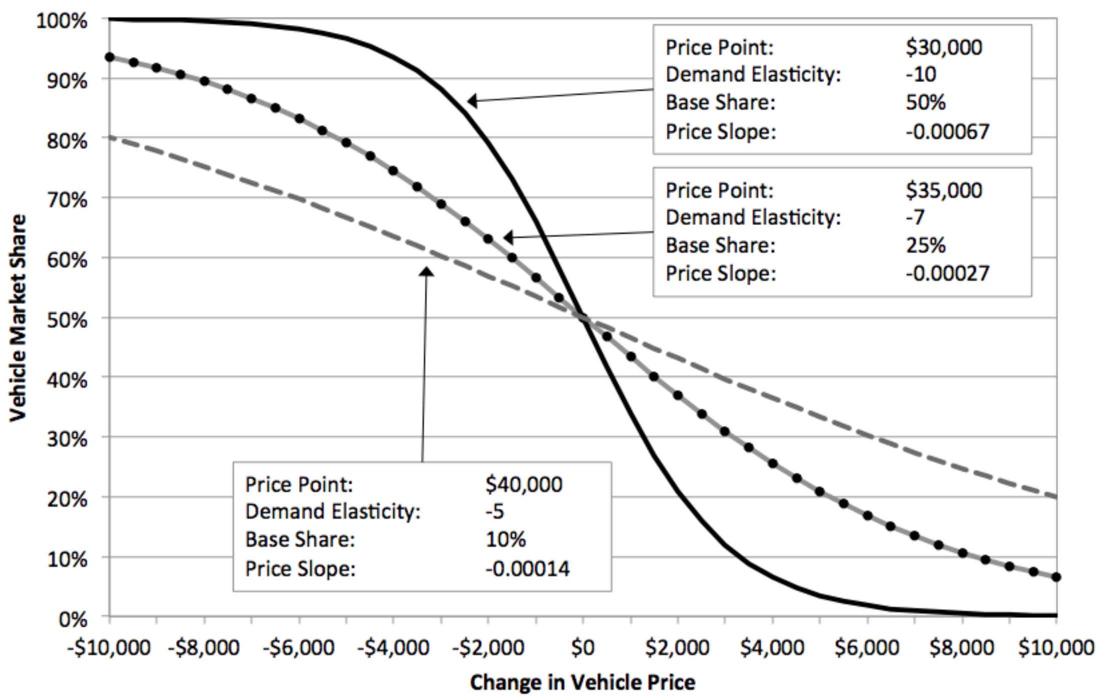
The demand elasticity of -5 is a major contribution to this inelastic market and is the same value assumed for BEVs and FCEVs below when considering the increase in market share due to a perceived or equivalent reduction in vehicle price due to increased refueling availability. This value is also applied for the CVRP analysis, as there is evidence that the current market base (consumer segment) for advanced vehicle is relatively unresponsive to vehicle price compared to typical consumers.

The benefit estimates presented below are based upon a relatively simple and transparent representation of changes in market share due to changes in effective consumer prices. However, this analytic framework can be extended to a broader assessment of the interactions between consumer preferences and vehicle attributes. As discussed in Chapter 5, an advantage of applying this analytic framework to projects supported through ARFVTP is the potential to calibrate the model to empirical data on future market outcomes and available data from either funded projects or proposals submitted in response to future funding opportunities. Examples

33 See footnote 32.

of applying this framework to explore future LDV markets and policy mechanisms are discussed in two recent reports that rely upon the LAVE-Trans model.[34,35]

Figure 19: Example of Changes in Market Share With Vehicle Price for Different Price Slopes



3.1.2 Increased Market Share due to Increased Industry Experience

Vehicle production cost-reduction benefits are calculated using two analytic frameworks: (1) unit cost reductions due to increased experience with a given technology, and (2) market share increases resulting from expected unit price reductions changes. This section reviews the experience curve framework as background for market transformation benefit calculations discussed below. Market share increases due to unit price reductions were discussed in the previous section.

Though the general trend of cost reductions through increased experience is backed by empirical evidence[36], there is often significant uncertainty about the magnitude of cost reductions that might be achieved at any particular experience level. Moreover, the types of interventions in the technology innovation process, on the part of either industry or government, that would most effectively move a technology down the experience curve or

34 NRC (2013). *Transitions to Alternative Vehicles and Fuels Committee on Transitions to Alternative Vehicles and Fuels*; Board on Energy and Environmental Systems; Division on Engineering and Physical Sciences, National Research Council. Washington, D.C.: The National Academies Press, http://www.nap.edu/catalog.php?record_id=18264.

35 See footnote 26.

36 See footnote 42.

change the slope of the curve are also uncertain.[37,38,39] While more detailed knowledge about the production and manufacturing of a new technology may help inform the effectiveness of intervention, there is some question about the feasibility of technology support programs integrating and assessing large volumes of detailed technical data across a broad portfolio of emerging technologies.[40] Market clearing prices and trends analyses, when combined with some degree of detailed understanding of technical advances and potential, can be relied upon to construct an analytic model of experience curves for future technologies. Based upon historical experience, such as cost escalations in the wind industry, there are legitimate concerns over the use of experience curves to predict future cost reductions due to policy interventions.[41] Ideally, sufficient information for particular technologies would be available to allow for more effective and targeted policy support. As this information emerges for new technologies, assessments of particular case studies or market trends will provide insight to guide policy formation and priorities. These trends can be revisited over time as new market data become available, although there can be some shortcomings to relying on prices as a proxy for production costs. (See discussion below.)

As indicated in Figure 20, unit cost reductions occur as cumulative experience deploying a particular technology increases.[42] Experience can be measured in various units, such as barrels per day of installed capacity for fuel production or total kilowatt hours (kWh) of storage capacity for battery technologies. For the schematic in Figure 20, technology costs decrease significantly in moving from R&D bench-scale units to demonstration units. When unit costs begin to approach those of incumbent technologies, such as gasoline fuel or internal combustion engine (ICE) vehicles, subsidies may be justified to push the competing technologies toward commercialization. Subsidies may come from private companies or government agencies. In company considerations of new product pricing, technologies may be subsidized internally to some degree to capture market share and secure brand recognition. For government agencies, new technologies are subsidized on the basis of the social and environmental benefits achieved

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37 PCAST (1999). *Powerful Partnerships: The Federal Role in International Cooperation on Energy Innovation*. Washington, D.C., President's Committee of Advisors on Science and Technology.

38 Norberg-Bohm, V., Ed. (2002). "The Role of Government in Energy Technology Innovation: Insights for Government Policy in the Energy Sector." Energy Technology Innovation Project, Belfer Center for Science and International Affairs, BSCIA Working Paper 2002-14.

39 Sagar, A. D. and J. P. Holdren (2002). "Assessing the global energy innovation system: some key issues." *Energy Policy* 30(6): 465-469.

40 Nemet, G. F. (2006). "Beyond the learning curve: factors influencing cost reductions in photovoltaics." *Energy Policy* 34(17): 3218-3232.

41 Grübler, A., Aguayo, F., Gallagher, K., Hekkert, M., Jiang, K., Mytelka, L., et al. (2012). "Policies for the Energy Technology Innovation System (ETIS)." *Global Energy Assessment: Toward a Sustainable Future,* 1665–1743.

42 Wene, C.-O. (2000). *Experience Curves for Energy Technology Policy.* Paris, Organisation for Economic Co-operation and Development, International Energy Agency.

through commercialization. Even when unit costs are above those of the incumbent technology, some portion of the population will be willing to pay a premium for these technologies. The premiums paid by early adopters are similar in effect to government subsidies, increasing revenue to producers and manufacturers and moving the technology further down the experience curve, resulting in lower unit costs for future consumers and (often) improving the competitiveness of the new technology. Once a new technology reaches a comparable cost basis, assuming all other attributes are equivalent or better than those of the incumbent technology, genuine market competition ensues, and subsidies and early adopters are no longer relied upon to the same degree to move further down the experience curve.

The experience curves in Figure 20 portray two possible outcomes as the cost of a competing technology approaches the cost of the incumbent technology. In this example, for the sake of simplicity, only a small range of uncertainty is indicated for the cost reduction that might be achieved by the incumbent technology, and by comparison a large range is indicated for the competing technology. The rapid technology innovation curve (solid thin line) indicates unit costs dropping below those of the incumbent technology, at which point a majority of the market would likely shift to the new technology (if other barriers to market entry have been removed, and if the technology is comparable to the incumbent technology in terms of performance or other attributes). In contrast, the moderate technology innovation curve (dashed thin line) indicates unit costs approaching but not dropping below those of the incumbent technology. In this case, the new technology may achieve some degree of limited market share and would need to offer consumers features or services that are valued above and beyond those of the incumbent technology to increase market share significantly. These attributes may be valued by a particular market segment, such as green consumers who consider impacts on the environment in their purchase decisions. If this market segment is limited, the competing technology may never reach cost parity with the incumbent technology, at least from the perspective of the mass market.

There is no guarantee that future cost reductions for a given technology will unfold in a smooth, continuous trajectory such as the experience curve schematic in Figure 20. Irregularities in cost-reduction trends have been observed in retrospective studies of particular technologies, reinforcing the fact that past trends are not a guarantee that future projections will continue those trends. For this discussion, the research team assumes that aggregate experience curves representing general technological systems, encompassing multiple novel components or systems, will tend to smooth out irregularities that occur with particular components.[43] Therefore, the learning metrics used in this represent clusters of technologies. For this reason, the learning rates (or progress ratios) employed are relatively conservative (that is, fewer cost

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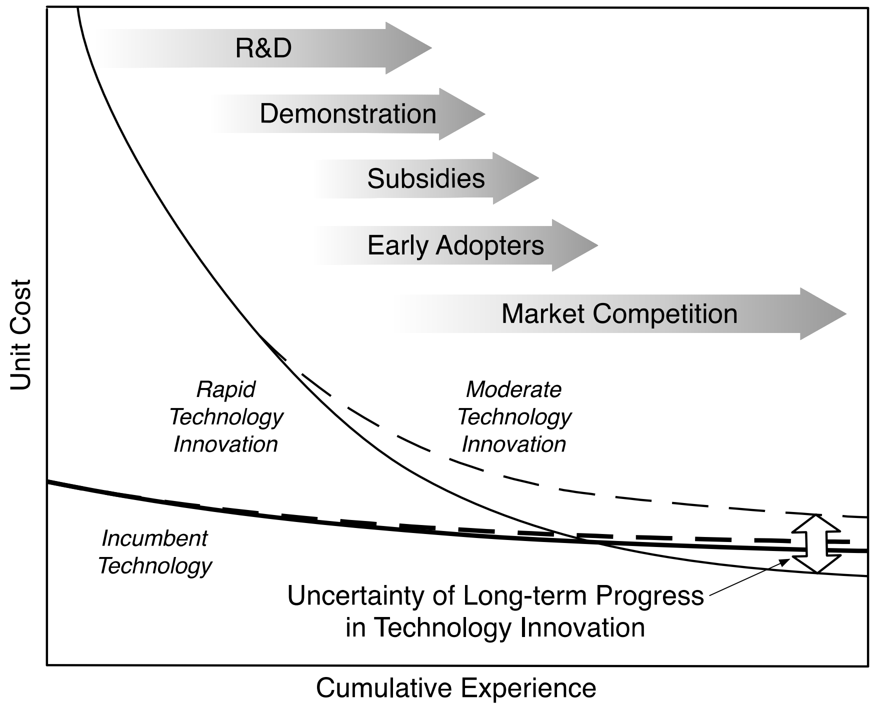
43 Developing a consistent representation of innovation dynamics and cost reductions due to experience across a broad range of technologies at a very granular level (for example, distinct learning curves for specific battery types) is a significant analytic undertaking and would require very large quantities of data on specific systems and subcomponents involved in all ARFVTP projects, as well as other incumbent and competing technologies.

reductions per increase in cumulative production) compared to those observed in some specific technologies or components.

Figure 20: Unit Cost Reductions due to Technology Innovation



The cost and market share gaps between these two possible outcomes highlights the important role of uncertainty in the long-term potential for unit cost reductions resulting from increased experience. This uncertainty may obscure the potential long-term market competitiveness of a given technology. Even when products are being subsidized and purchased by early adopters, and costs appear to be dropping as a result, the longer-term cost reduction potential may be highly uncertain. Moreover, the incumbent technology is likely to experience additional cost reductions with cumulated experience and may undergo additional innovation in response to competition, further complicating efforts to estimate the long-term market share potential of a new technology.

The relationship between policy support mechanisms and anticipated but uncertain cost reductions for new technologies highlights the importance of tracking technology progress as a new technology moves toward and into the commercialization and market competition phase. Ideally, policy makers would have full information about technology cost status and anticipated cost-reduction potential. However, in reality, some degree of information asymmetry will always exist between policy makers and technology suppliers, and suppliers themselves must protect internal information about cost-reduction potential or technology performance to maintain competitive advantage and to make strategic decisions.

Product price is often considered an indicator of a producer's cost structure and the market readiness of a particular technology. In theory, producers will maintain a profit margin between the total cost of bringing a product to market and the price charged to consumers. However, for new technologies with steep learning curves, producers may have incentive to drop prices below the cost of production, for limited periods, to maintain competitive advantage. The resulting revenue shortfall would be closed by internal cross-subsidies, with revenues from other products sold by the same company. The possibility of this behavior exacerbates the uncertainty around estimating future cost reduction potentials and must be taken into account to understand the experience curve framework. Market price is only one indicator that government agencies must consider in deciding support a particular technology or a portfolio of technologies. Figure 21 indicates shifts in the relationship between price and cost as a technology moves through five phases of the experience curve on the path to widespread commercialization:[44]

A. **Initial Product Deployment.** The price of a new product may be below the actual unit cost when the product is introduced into a given market. Revenue from these initial sales may support the development of the next-generation product, but internal cross-subsidies (from revenues generated by other products sold by the company, for example) will also support this development.

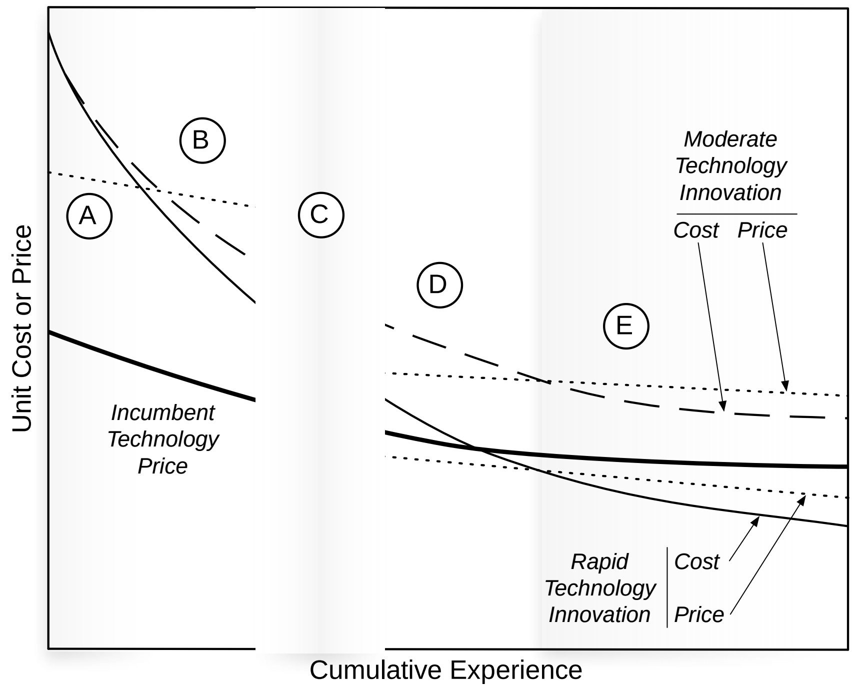
B. **Price Umbrella.** As costs drop and volumes increase for subsequent product generations, a producer will be under pressure to both recover net losses from Phase A and generate revenue for investments in additional product development and ramp-up in production capacity for subsequent product generations. This is indicated in Phase B as a price umbrella, with prices declining only slightly relative to cost reductions. Figure 21 shows two possible trends for the aggregate cost curve of the same product being supplied by two producers. In general, greater revenue would be generated during this phase for the company with the more rapid technology innovation cost curve. The company with slower cost reductions would be under greater pressure to extend the price umbrella for a longer period (or over a larger number of units).

C. **Shakeout**. The price umbrella in Phase B can endure as long as producers are maintaining or increasing market share, but this growth may be limited to relatively small niche markets. As product volumes increase and relative costs among producers shift, a shakeout period will eventually occur. This typically involves prices dropping to just above the cost curve, eliminating the price umbrella. Figure 21 indicates an extreme and less likely scenario, with prices dropping below the cost curve, as occurred in Phase A. This would be a strategic decision on the part of a producer introducing a key product into a large and highly competitive market, such as light-duty vehicles. The two scenarios shown in Figure 21 are distinct in that the new price level for the moderate technology innovation curve is still above that of the incumbent technology, while the new price level for the rapid technology innovation curve is at or below the price of the incumbent technology. The resulting change in expected market share of the new

44 Wene, C.-O. (2000). *Experience Curves for Energy Technology Policy*. Paris: Organisation for Economic Co-operation and Development, International Energy Agency.

product would be significant. Unlike the simple depiction in Figure 21, the shakeout phase can be prolonged with multiple price shifts, again exacerbating the uncertainty around actual cost reduction potentials. Market prices during this phase may be a poor indicator of the production cost structure of a technology. Some producers may discontinue products during this phase or shift the core technology to products sold in other markets or subniches of the original market.

Figure 21: Relationship Between Unit Cost and Price Through Five Stages of Commercialization



D. Early Market Competition. After a shakeout period, producers must maintain growing market share by competing with either other new technologies in higher-end market segments (for example, hybrid electric vehicle markets) or by competing directly with mass-market incumbent technologies (for example, biofuels in gasoline or diesel markets). These two cases are indicated in Figure 21 by the moderate and rapid technology innovation scenarios, respectively. If increasing sales volumes and sufficient profits can be maintained without dropping prices below the cost curve, then Phase D is essentially avoided as a product eventually enters commercialization, Phase E. However, if early market competition encourages companies to drop prices below the cost curve, as occurred in Phase A, additional revenue in addition to product sales must be received to move further down the experience curve and remain competitive into the commercialization phase. As depicted in Figure 20, this revenue may be a mix of government subsidies and premiums paid by early adopters. If market growth cannot be maintained during this phase, additional revenue may be required even if prices do not drop below costs; this distinction can be obscured from supporting government agencies due to the great uncertainty around cost-reduction potentials and associated long-term market potentials. For example, a public agency would interpret the price level in Phase

D for the moderate technology innovation curve very differently if the actual cost curve were closer to the rapid technology innovation curve.

E. **Commercialization**. A stable profit margin is maintained between prices and costs. The product associated with the moderate technology innovation curve may be confined to a niche market, while the product associated with the rapid technology innovation curve would tend to outcompete the incumbent technology, if all other attributes are comparable and market barriers removed.

The uncertainty around cost-reduction potentials associated with experience curves is not only an issue relevant to program design and funding priorities, it is also a central issue associated with society's ability to address climate change in general, as reflected in the results from energy economic models of climate change. Given the deep reductions in GHG emissions required over time to achieve climate stability, very low-carbon technologies, some being relatively new, must achieve widespread commercial success. Ensuring that very low-carbon technologies with significant long-term market potential endure the market dynamics discussed above must be an objective of successful climate change policies. Pressure to meet carbon effectiveness metrics (based upon cost-benefit evaluations, for example) too early in the market transformation process can result in entrenchment of moderately low-carbon technologies and a tendency to shut out more promising long-term options.[45] Various studies have provided examples of transportation technology adoption scenarios that meet very low GHG emissions across the sector.[46]

Sections 3.2, 3.3, and 3.4 below review benefit estimates due to market share increases resulting from three activities supported by ARFVTP: (1) ZEV rebates provide to PHEVs, BEVs, and FCEVs through the CVRP; (2) increased availability of public EVSE stations for PHEVs and BEVs; and (3) increased availability of hydrogen fueling stations for FCEVs. In each case, an increase in market share is estimated based upon the influence of each activity on the effective price of ZEVs for consumers. GHG and petroleum fuel reduction benefits are determined based upon increased ZEV market share displacing conventional ICE gasoline vehicles. Table 13 briefly describes methods used for each market transformation benefit type, which are described in more detail in the following sections.

45 Unruh, G. C. (2002). :Escaping carbon lock-in." *Energy Policy*, 30(4), 317–325.

46 McCollum, D., and C. Yang. (2009). "Achieving deep reductions in US transport greenhouse gas emissions: Scenario analysis and policy implications." *Energy Policy*, 37(12), 5580–5596. doi:10.1016/j.enpol.2009.08.038.

Table 13: Summary of Estimation Methods for Investments on CVRP, Refueling Infrastructure, and Vehicle Production

Benefit category	Method description
CVRP 1. Retrospective 2. Projection	Two types of benefits are estimated for the CVRP: retrospective benefit from 2011 to the first quarter (1Q) of 2014 and projection beyond the 1Q of 2014. Retrospective benefit is estimated by two-choice logit model for direct vehicle price reduction from rebates. Projected additional sales are estimated by modeling the learning effect from the total CVRP funding as of the 1Q of 2014 that vehicle price reduction will be induced by the government investment, same as that for investment on vehicle production.
Refueling infrastructure (EVSE and hydrogen stations)	EVSE: increased utility from increased availability of EVSE is valued as vehicle purchase price reduction based on the NRC study (2013). Hydrogen stations: perceived cost penalty reduction is estimated based on previous studies and valued as vehicle purchase price reduction. The vehicle price reduction benefit is assumed to take years (till 2020) to reach and remain the level beyond the ramp-up period.
Vehicle production (EV components and manufacturing)	The additional vehicle sales are estimated by consumer surplus change as learning effect from the investment.

3.2 Influence of the Clean Vehicle Rebate Program

In this analysis, the research team estimates two types of benefits from the CVRP: (1) a retrospective study with the most recent data available, and (2) additional sales projected due to learning effect cost reductions. The retrospective study estimates the ZEV sales attributable to the direct rebates to date since the program began. Projections from the learning effect focus on additional sales due to ZEV cost reduction as a result of the total CVRP funding to date.

For the retrospective study from the beginning of 2011 to the first quarter of 2014, the present analysis of the potential influence of CVRP rebates on consumer decisions involves two analysis approaches. First, a high ZEV adoption rate is estimated based upon the logit model framework discussed above. Second, a low ZEV adoption rate is estimated based upon a simulation of consumer preferences for attributes for specific ZEV makes and models. These methods serve as the basis for the high and low market transformation benefits for the CVRP program.

The general approach for projecting future market share increases resulting from price reductions due to CVRP and due to increased industry experience are discussed above in Sections 3.1.1 and 3.1.2, respectively. The estimation method is the same as that in Section 3.4 for the influence of investments in vehicle production.

These benefit estimates for CVRP are preliminary and general and should be improved upon through more detailed analyses conducted in future studies. The results presented here are not intended to inform or critique the design or implementation of the CVRP. The estimates have been developed using an analytic framework that can be applied consistently across other ARFVTP activities influencing ZEV prices. The framework enhancements discussed in Section 5.2 are examples of analytic methods required to examine the effectiveness of CVRP in detail.

The input assumptions relied upon for the logit model calculations for the CVRP are summarized in Table 14. For the sake of simplicity, it is assumed that PHEVs received $1,500 rebates, and both BEVs and FCEVs receive $2,500 rebates. In actuality, rebates are awarded based upon a broader range of vehicle attributes. As discussed above, the price points for the ZEV technologies are determined based upon National Research Council (NRC) cost estimates, rather than prices revealed through market transactions.[47] As indicated, ZEVs (P_{NewLDV}) are assumed to compete against vehicles ($P_{Incumbent}$) with price points equivalent to hybrid electric vehicles (HEVs). Two key assumptions determine the majority of the differences between the high and low estimates. First, the demand elasticity is assumed to be -5 for the low case and -7 for the high case. Second, the low-case market share results are assumed to be about 50 percent less than the high-case results, based upon preliminary consumer preference market share estimates (see below). This second assumption is applied to PHEVs, BEVs, and FCEVs, though model-specific attributes for new FCEVs are not available to allow for comparable consumer preference simulations. The result of these assumptions for FCEVs, combined with the higher vehicle price point in the low case ($65,000 compared to $50,000) and narrower base market share (2.5 percent compared to 10 percent) dampens FCEV sales in the low case to a greater degree than in the low cases for PHEVs and BEVs. The resulting wider range of uncertainty around market transformation benefits associated with FCEVs is consistent with the lack of real-world data on early vehicle model attributes and market acceptance trends compared to PHEVs or BEVs.

Table 14 also indicates the price slope resulting from the market share and vehicle price assumptions, as well as the percentage change in market share (as a percentage of the base market share, as discussed above).

Based upon data available through the second quarter of 2013, some 59,100 CVRP rebates had been awarded, with an average of $2,100 per award and total funding of $123.6 million. In reality, some of these vehicles would have been purchased regardless of the availability of CVRP funds. This fraction of vehicles was estimated using a consumer choice model comparing the attributes of the electric-drive vehicle to the attributes of a comparable gasoline vehicle. The model used, the ADOPT model developed and maintained at NREL, takes into account consumer valuation of attributes such as acceleration, range, and interior volumes. It also considers consumer attributes, such as income and education. These attributes are weighed against vehicle MSRP to estimate market share among all makes and models available within the LDV market. The analysis suggests that many consumers would have purchased the electric-drive version of the vehicle based upon relative vehicle performance attributes and original MSRP, even without the CVRP rebate. In effect, the low-case benefit results do not suggest that the high-case benefits are not realized, but rather that only a portion of the high-case benefits can be attributed to funds provided by CVRP, and the remainder are attributed to consumer behavior. As with other high- and low-case calculations, the most likely estimate is presumed to fall somewhere between these two estimates.

47 See footnote 1.

These results are preliminary and serve as an adjustment to develop a low-case estimate of benefits associated with CVRP rebates. More detailed analysis of the influence of the CVRP on consumer behavior is certainly warranted, and the present analysis using ADOPT could be improved in several ways. One of the key challenges is accounting for preferences of early adopters compared to other consumer segments. As PEV sales increase, more statistical data will become available on preferences associated with electric-drive vehicle attributes.

A more refined version of this simulation would involve separate model runs for each ZIP code area where CVRP vehicles were sold. This would give slightly different results due to the unique attributes of consumers in particular ZIP codes, such as average household income level. In general, higher income households would tend to be somewhat less sensitive to the influence of rebates on their purchase decisions. On the other hand, statistical data on past vehicle purchase behavior may reveal that consumers within these ZIP code place a high premium on particular vehicle attributes, such as "greenness" or high-tech appeal.

Effects on annual sales for PHEVs, BEVs, and FCEVs continue into the future, based upon an assumption that supporting policies remain in place. The resulting trends are indicated on an annual basis for each vehicle type in Figure 22 and are compared to market share increases comparable to those required for the ZEV compliance scenarios or *ZEV Action Plan* goal.[48,49] The resulting reductions in GHGs and petroleum use are indicated in Figures 23, 24, and 25.

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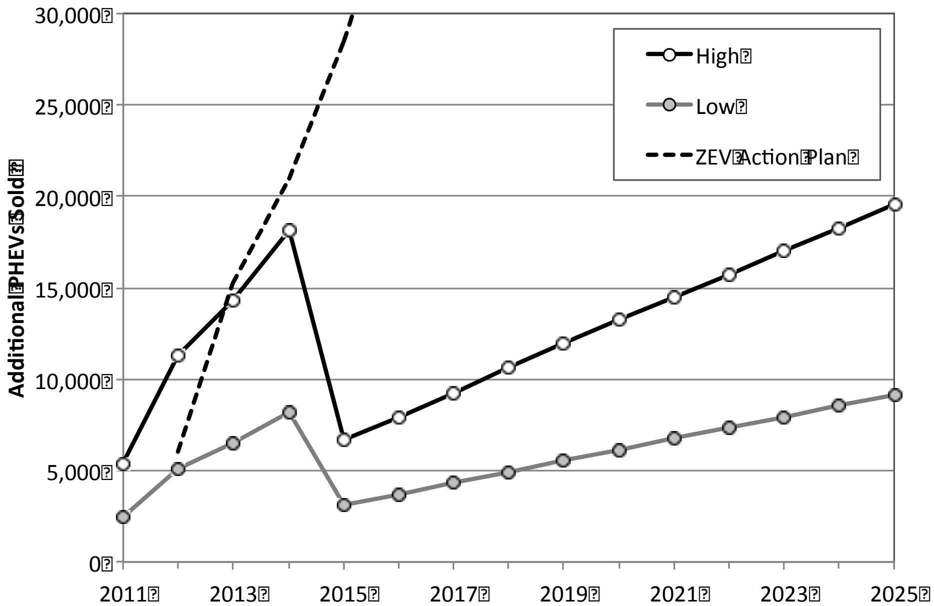
48 CARB. (2011). Staff Report: Initial Statement of Reasons. California Air Resources Board. Available online at: www.arb.ca.gov/regact/2012/zev2012/zevisor.pdf

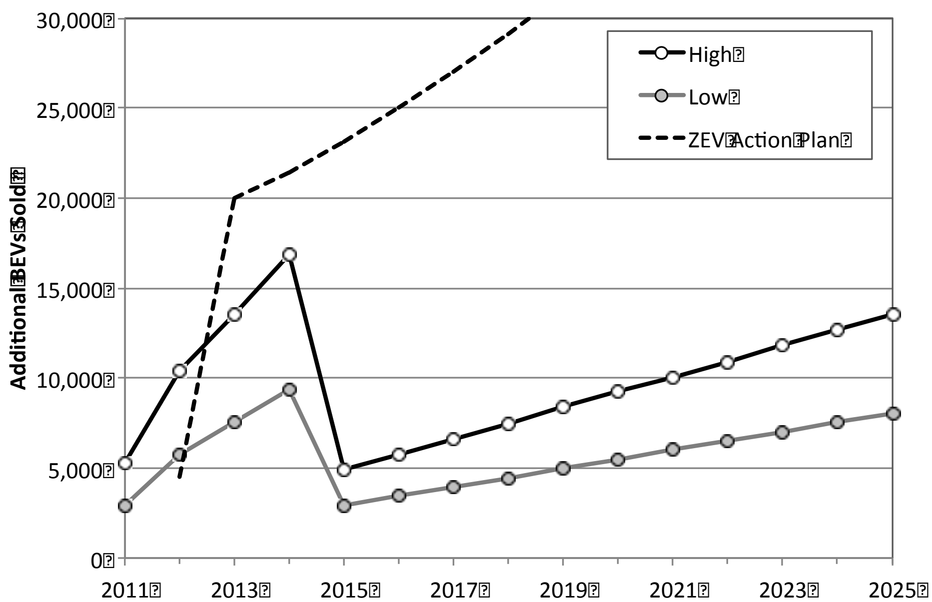
49 GIWG. (2013). 2013 ZEV Action Plan: A roadmap toward 1.5 million zero-emission vehicles on California roadways by 2025. Governor's Interagency Working Group on Zero-emission Vehicles, available online at: opr.ca.gov/docs/Governor's_Office_ZEV_Action_Plan_(02-13).pdf

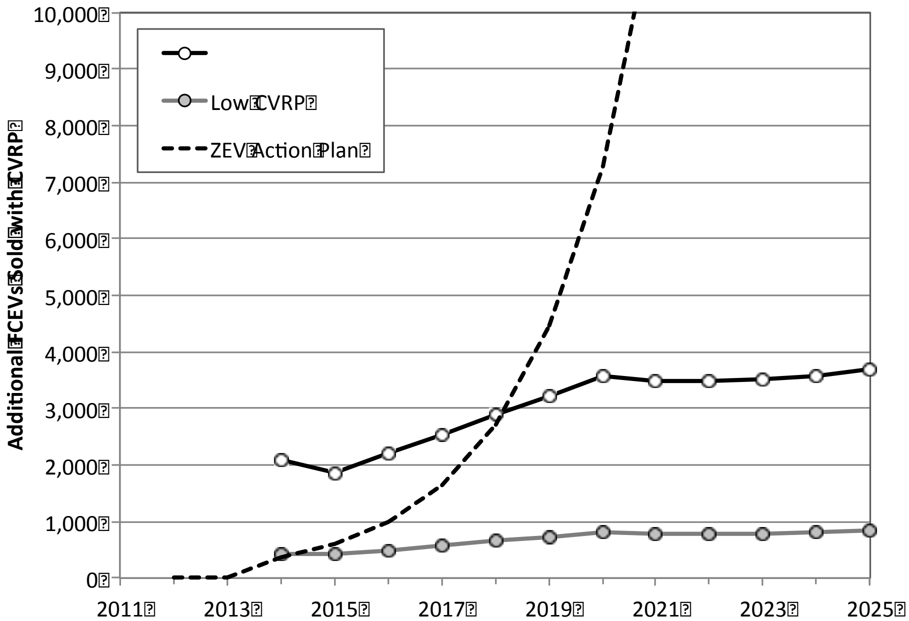
Table 14: Assumptions for Retrospective and Future CVRP Market Share Calculations

Case	CVRP Incentive	Demand Elasticity	P-Incumbent	P-New LDV	Price Slope	Change in Demand	Consumer Choice Penalty for Low Case
PHEVs			***HEV LDV***	***PHEV (woCVRP)***			
Low	-$1,500	-5	$34,213	$40,013	-0.00016	5.17% (retrospective) 1.59% (future)	55%
High	-$1,500	-7	$34,213	$40,013	-0.00023	6.23% (retrospective) 1.86% (future)	na
BEVs			***HEV Car***	***BEV Car (woCVRP)***			
Low	-$2,500	-5	$30,728	$41,102	-0.00016	6.11% (retrospective) 1.57% (future)	53%
High	-$2,500	-7	$30,728	$41,102	-0.00022	5.78% (retrospective) 1.39% (future)	na
FCEVs			***HEV LDV***	***FCEV (woCVRP)***			
Low	-$2,500	-5	$34,213	$65,000	-0.00013	0.70% (retrospective) 0.04% (future)	50%
High	-$2,500	-7	$34,213	$50,000	-0.00019	2.58% (retrospective) 0.12% (future)	na

Figure 22: High- and Low-Case Increases in PHEVs, BEVs, and FCEVs due to CVRP

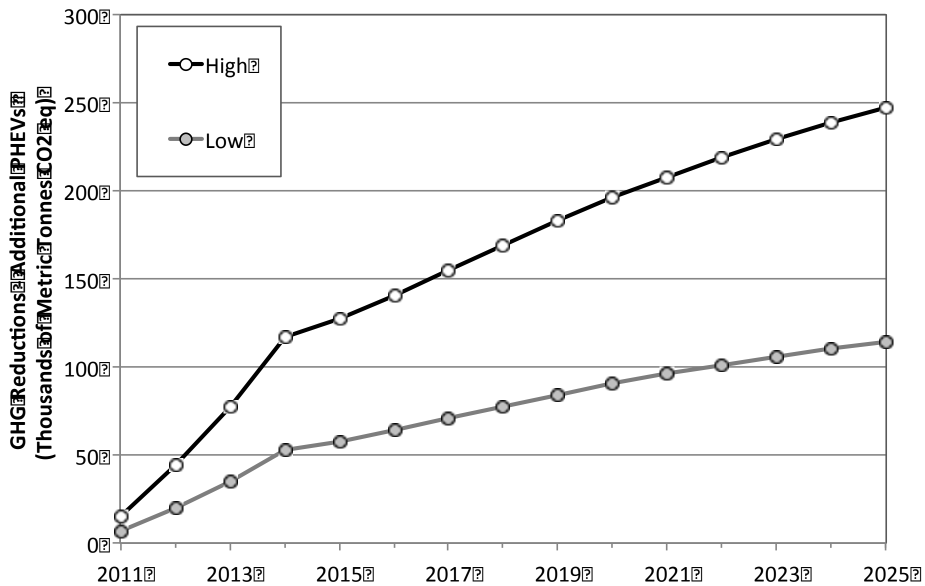






10,000
9,000
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
Additional FCEVs Sold with CVRP
Low CVRP
ZEV Action Plan
2011
2013
2015
2017
2019
2021
2023
2025

Figure 23: GHG and Petroleum Fuel Reductions Resulting From High- and Low-Case PHEV Market Share Increases due to CVRP



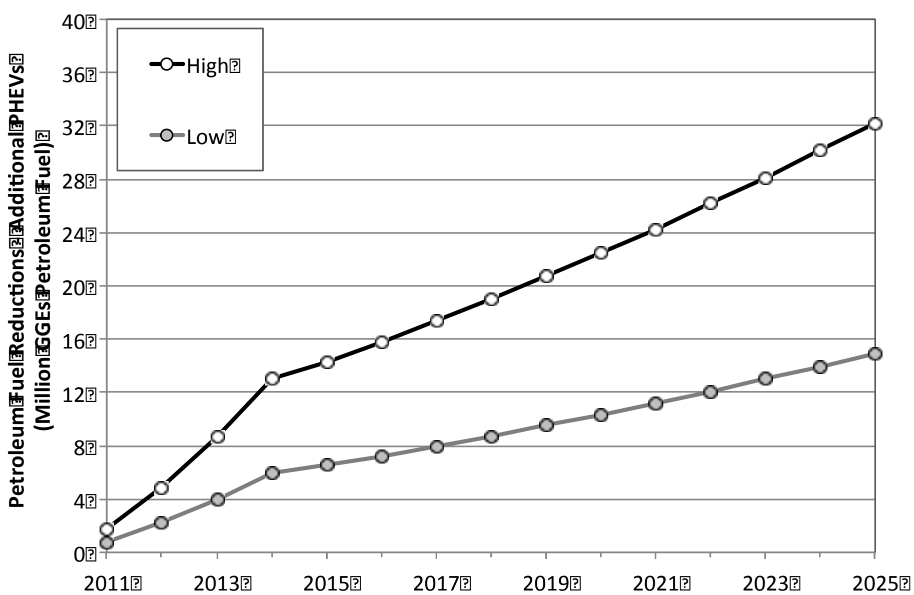
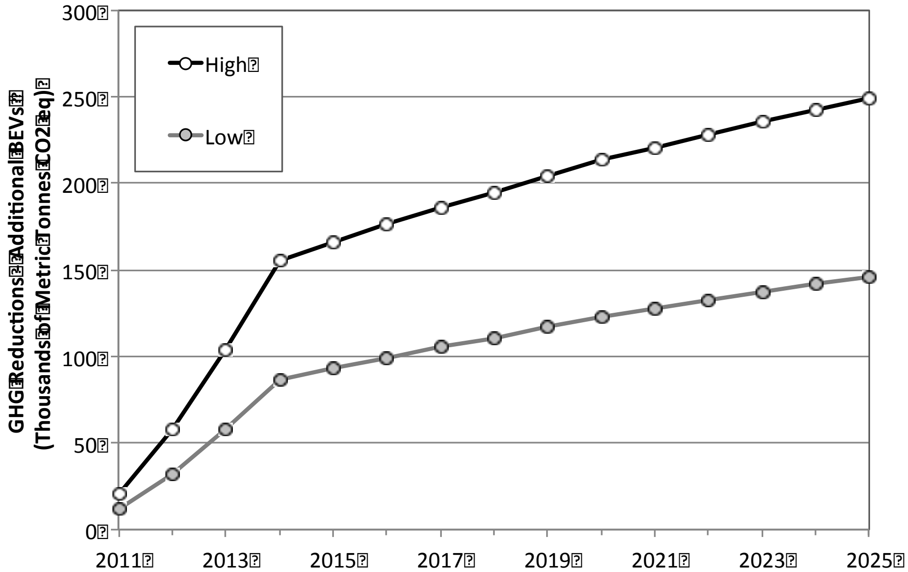


Figure 24: GHG and Petroleum Fuel Reductions Resulting From High- and Low-Case BEV Market Share Increases due to CVRP



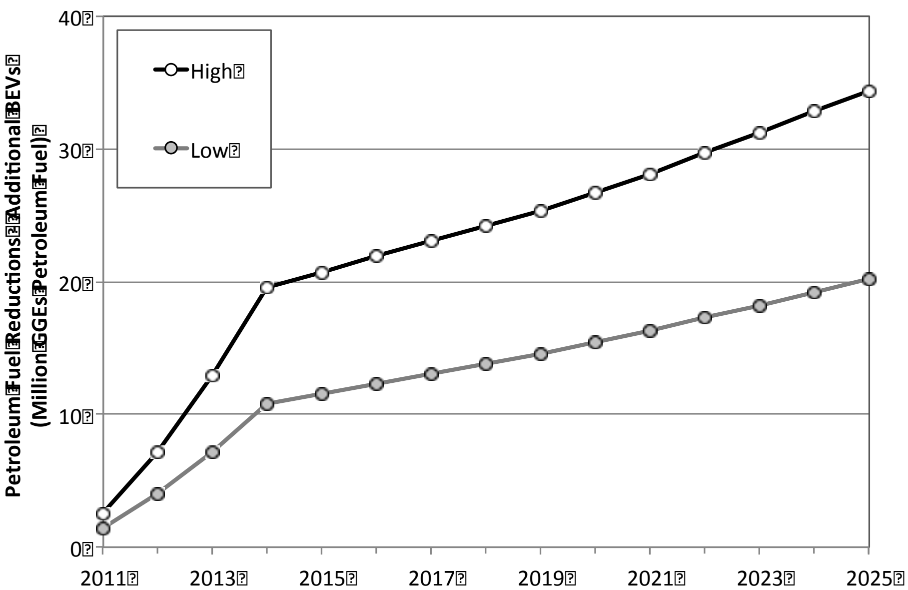
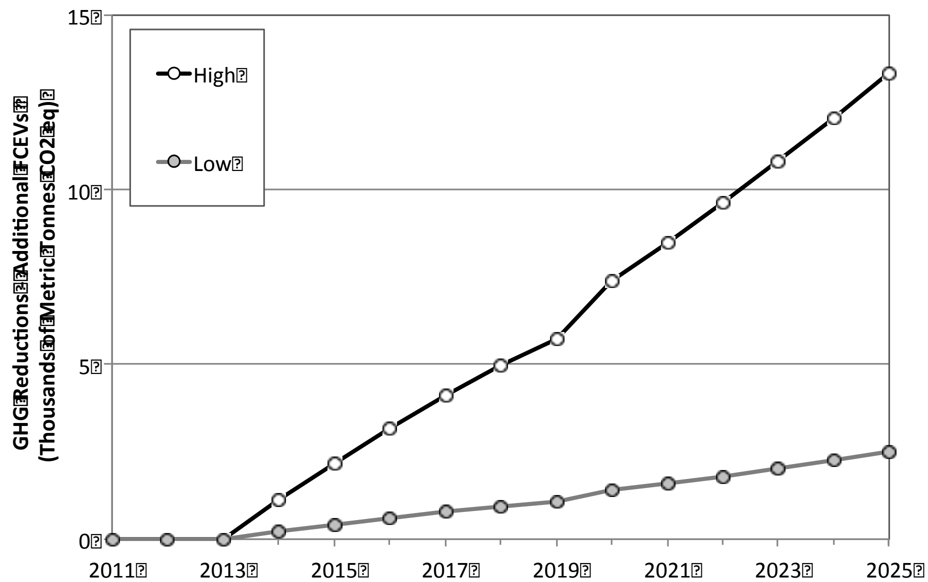
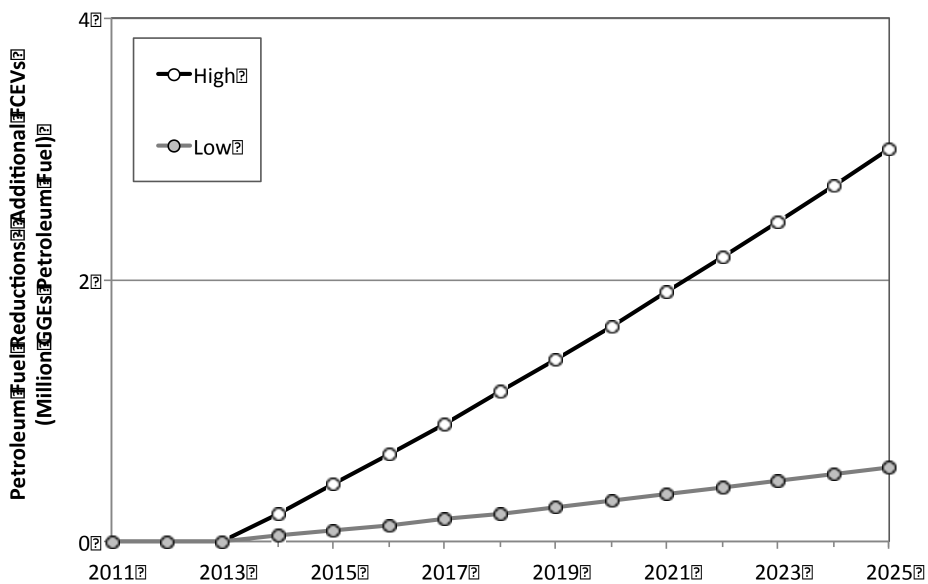


Figure 25: GHG and Petroleum Fuel Reductions Resulting From High- and Low-Case FCEV Market Share Increases due to CVRP





3.3 Increased Availability of Refueling Infrastructure

Refueling station availability is critical to the market success of dedicated alternative fuel vehicles, such as hydrogen, CNG, or battery electric vehicles. It is also essential to increased alternative fuel use by bifuel vehicles such as PHEVs, E85 flex-fuel vehicles, or CNG bifuel vehicles. The relationship between EVSE availability and BEV utility or an increase in PHEV e-miles is highly uncertain, though interactions are beginning to be revealed as vehicles and EVSE stations are deployed jointly in select markets. A key issue is the degree to which public and workplace charging can enhance the utility and e-miles from PHEVs and BEVs, which will likely be charged at home for most e-miles. PHEVs and BEVs can be sold to households that are not located near public EVSE stations, but the availability of public EVSE stations will increase the value of PHEVs and BEVs to consumers. In contrast, station availability is a fundamental aspect of the deployment of dedicated hydrogen vehicles. This section focuses on the benefits associated with public EVSE stations and hydrogen refueling stations (HRS) supported.

The importance of station availability for early FCEV markets cannot be understated. Hydrogen vehicles simply cannot refuel without access to stations, and consumers are accustomed to a high degree of convenience from existing gasoline stations.[50] However, determining how many stations are needed to support particular markets as they grow over time is challenging. Travel time models developed by researchers at UC Davis and UC Irvine have calculated the driving distances or times for particular consumer markets or neighborhoods as a function of the number of stations distributed across an urban area.[51, 52] Assuming some inconvenience cost or cost of time spent driving, and discounting these costs as they might accrue over time to a net present value, a penalty against the purchase price of a vehicle can be estimated. This approach estimates a rational actor model of consumer behavior, representing consumer decisions derived from a logical and objective consideration of economic utility factors. As has been discussed elsewhere, vehicle purchase price penalties from these driving simulations or economic valuations tend to be lower than penalties suggested in stated preference surveys. For this analysis, the research team relies upon stated preference penalty estimates from an extensive survey of consumers in different cities and then estimates the corresponding increase in market share associated with installing additional HRS.[53]

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50 Home refueling has been offered for hydrogen vehicles from some suppliers but proves challenging due to high-pressure requirements and capital costs.

51 Nicholas, M. A., S. L. Handy and D. Sperling (2004). "Using Geographic Information Systems to Evaluate Siting and Networks of Hydrogen Stations." *Transportation Research Record* 1880: 126-134.

52 Stephens-Romero, S. D., T. M. Brown, J. E. Kang, W. W. Recker and G. S. Samuelsen (2010). "Systematic planning to optimize investments in hydrogen infrastructure deployment." *International Journal of Hydrogen Energy* 35(10): 4652-4667.

53 Melaina, M., J. Bremson, and K. Solo. (2012). “Consumer convenience and the availability of retail stations as a market barrier for alternative fuel vehicles.” Presented at the 31st USAEE/IAEE North American Conference, Austin, TX, November 4-7.

Comparable stated preference data are not available for the responsiveness of consumers to the availability of EVSE stations. Though several studies have been conducted to simulate how typical drivers might require or use public EVSE, data on how the consumer vehicle purchase decision might be influenced by public EVSE are limited. To determine the value of public EVSE charging to potential vehicle purchasers, the research team tailors a general representation from a recent NRC study to the four major California urban areas: Bay Area, Sacramento, Los Angeles, and San Diego. The NRC representation of public EVSE is a benefit to consumers that increases with greater prevalence, as measured in vehicle charges provided compared to vehicle refills provided by existing gasoline stations. The NRC report also includes a representation of the cost penalty for hydrogen stations, which is comparable to the stated preference results used here.[54]

Following this logic, the influence of workplace and public EVSE is treated as an added value to PEVs beyond that provided by home charging, while increased availability of HRS reduces a predetermined cost penalty associated with very low availability during the early market introduction phase. Details of this analytic approach are provided in the sections below.

This treatment of the influence of installing EVSE and HRS only partially captures the market transformation benefits associated with additional availability. Additional data are needed on the influence of both retail infrastructure technologies to develop better estimates on market dynamics. In particular, the benefits of public or workplace EVSE compared to home charging are poorly understood, and an evaluation of the increased e-miles driven as a result of additional public EVSE is not included in the present analysis and could prove to be substantial. A more rigorous treatment of these benefits should prove feasible as additional data on market dynamics and consumer behavior are collected.

3.3.1 Increased Availability of Electric Vehicle Supply Equipment (EVSE)

The approximate number of EVSE stations to be installed through ARFVTP awards in various cities is summarized in Table 15. Most of these EVSE stations are explicitly identified as having specific urban areas determined for deployment. A handful of awards, however, do not explicitly identify where all of the EVSE stations will be installed. These stations are summarized in Table 16. For this report, the research team assumes that these additional EVSE stations are distributed across the four major metro areas in proportion to the population within each area. This distribution is indicated in Table 17, with nearly 60 percent of the EVSE stations going to the L.A. Basin, and one direct current fast charging (DCFC) station in each of the four metro areas except the L.A. Basin, which receives four DCFC stations. Populations in the four urban areas are based upon 2012 Census Urban Area designations, with the Bay Area and L.A. Basin both consisting of two urban areas, as noted in Table 17.

An increase in the availability of EVSE stations in a given urban area will increase the utility of PEVs sold in that urban area. The increased utility will be due to extended all-electric range and fuel savings. The research team adopts the approach for valuing the increased utility

54 NRC 2013, p 348.

reported in the recent NRC study, which determines an increase in the perceived value of PEVs as a function of the increased service of recharging. The 2013 NRC study relies upon the LAVE-Trans vehicle choice model, which considers nine variables in determining future market shares of alternative and advanced vehicle technologies. Public recharging availability is one of the nine factors for BEV and PHEV choices. Based on an analysis by Lin and Greene (2011a), the NRC study models the value of the availability of public recharging as "a function of the present value of full availability of public recharging versus none." The potential value of public charging is determined based upon an estimate of the additional cost of renting a conventional vehicle for trips or days when a limited-range BEVs is not sufficient.[55] The equation used in the LAVE-Trans model for the value of public EVSE stations (V_c) is:

$$V_c = \beta V\left(1 - e^{bf}\right)$$

Where,

β = the coefficient of vehicle price
V = the present value of unlimited public recharging
f = the availability of public EVSE stations relative to gasoline stations
b = slope coefficient

As used in the NRC study, the research team assumes β=1, V_PHEV=$1000 with a low of $500 and a high of $1,500 for PHEV and V_BEV=$500 with a low of $0 and a high of $1,000 for BEV. (Cost of range anxiety reduces the value of public recharging availability for BEV.) The resulting change to the PEV price is indicated in Figure 26 as a function of the EVSE service rate.

The value of public EVSE stations to PHEVs is determined using the same function but with a different set of parameters. The NRC study notes, "This method is very approximate and should be improved."(p. 349). To estimate the benefits of different levels of EVSE availability in each of the four major urban areas, the research team assumes a nominal gasoline usage rate (refills per day) unique to each city (based upon Polk data for LDVs per person per planning region, and gasoline stations per urban area) and nominal charges per day per EVSE station, as indicated in Table 18. Taking estimates for EVSE stations in place before and after installation of ARFVTP-supported stations (Table 20, discussed below), the research team calculates a unique set of EVSE availability values (*f*) for PHEVs and BEVs in each city before and after the installation or EVSE stations supported by ARFVTP.

The general equation for the availability of public EVSE stations, or service rate, is the ratio of recharges per day provided through EVSE stations to the number of refills per day provided by conventional gasoline stations. The research team unbundles the service rate parameters to incorporate estimates of EVSE and gasoline stations serving each of the major California urban areas, and the average number of charges or refills per day per station. The assumptions about gasoline refills and charges provided (or service potential provided, in the case that some EVSE

55 Lin, Zhenhong and D. L. Greene (2011). "Promoting the Market for Plug-In Hybrid and Battery Electric Vehicles: Role of Recharge Availability," *Transportation Research Record,* pp. 49-56.

stations are initially underused) per day per station are indicated in Table 18. The gasoline refill numbers are based upon approximate number of LDVs in each urban area and proprietary data on gasoline stations in California. The assumptions on charge events (or average potential charge events) per EVSE station are taken from ranges estimated in the *Statewide EVSE Infrastructure Assessment*.[56] The total number of gasoline stations and EVSE stations, before and after deployment of the EVSE stations supported by ARFVTP, is shown by urban area in Table 17.

The resulting vehicle purchase price equivalent benefit to consumers due to increased public EVSE availability in each of the major urban areas is indicated in Table 21. These values are used to estimate the subsequent change in market share that results when consumers within the market segments for PHEVs and BEVs see those vehicles as being more valuable due to the increase in the service rate from ARFVTP EVSE stations. It is assumed that the perceived vehicle price benefits take several years to reach as the total number of EVSE stations increases over time. In early years, only a few EVSE stations are available, and consumers perceive less benefit. As the number of EVSE stations accumulates, the perceived benefits (ΔP) will rise. For simplification, the perceived vehicle price benefits are assumed to increase linearly over the years until 2020 and then remain the level beyond the ramp-up, as shown in Figure 27.

The assumptions for sales increase calculations are shown in Table 19. The research team assumes that this increased sales level is maintained for eight years, starting in 2014, and then is reduced to half the rate in the ninth year and is phased out in the tenth year. This schedule is intended to approximate the average lifetime of the EVSE stations and the influence of these stations on consumer behavior, though empirical data on typical public EVSE turnover rates could improve this estimate. In a growing ZEV market, much larger volumes of EVSE stations will be deployed in addition to these early ARFVTP stations. The additional PHEVs and BEVs deployed per year for each case are shown in Figure 28. The resulting reductions in GHGs are shown in Figure 29, and the resulting reductions in petroleum fuel use are shown in Figure 30.

56 See footnote 18.

Table 15: ARFVTP EVSE Stations by City

City or Urban Area	Recipient	Agreement Number	L2 Public EVSE	DC Fast Chargers
Sacramento				
	Sacramento Municipal Utility District (SMUD)	ARV-10-034 (ARRA match)	22	-
	Sacramento Municipal Utility District (SMUD)	ARV-10-041 (ARRA match)	15	-
	California Department of General Services (DGS) Office of Fleet and Asset Management (OFAM)	ARV-12-011	9	-
	El Dorado County - Air Quality Management District and Facilities Div	ARV-13-XXX	10	
	Clean Fuel Connection, Inc.	ARV-13-022	4	
	International Association of Nanotech (dba) US Green Vehicle Council	ARV-13-XXX		2
	State of California, Department of Transportation (Caltrans)	ARV-13-XXX	2	
	General Distribution	various	83	1
	TOTAL		145	3
Bay Area				
	Association of Bay Area Governments	ARV-10-032	241	18
	Schneider Electric USA, Inc.	ARV-12-038	18	-
	Clean Fuel Connection, Inc.	ARV-13-022	12	
	The Vehicle-Grid-Integration Alliance	ARV-13-XXX	25	
	California EV Alliance	ARV-13-032	74	
	The Fremont Chamber of Commerce	ARV-13-XXX	10	2
	Silicon Valley Leadership Group Foundation DBA Bay Area Climate Collaborative	ARV-13-XXX	78	
	Bay Area Air Quality Management District	ARV-13-XXX	12	10
	Electric Power Research Institute	ARV-13-XXX	48	
	Golden Gate National Parks Conservancy	ARV-13-XXX	4	
	Bio-Rad Laboratories, Inc.	ARV-13-023	18	
	Adopt A Charger	ARV-13-XXX	3	
	International Association of Nanotech (dba) US Green Vehicle Council	ARV-13-XXX		5
	State of California, Department of Transportation (Caltrans)	ARV-13-XXX	5	
	General Distribution	various	238	1
	TOTAL		786	36
LA Basin				
	EV Connect, LA County MTA	ARV-10-006	20	-
	Southern California Regional Collaborative	ARV-10-045	315	-
	University of California, Irvine	ARV-10-046	19	-
	Los Angeles Department of Water and Power	ARV-12-065	32	-
	Los Angeles Department of Water and Power	ARV-12-051	32	-
	South Coast Air Quality Management District	ARV-12-053	-	17
	South Coast Air Quality Management District	ARV-13-026	6	
	City of Burbank	ARV-13-XXX	8	
	County of Riverside	ARV-13-XXX	82	4

	Good Samaritan Hospital	ARV-13-XXX	24	
	Los Angeles Department of Water and Power	ARV-13-XXX	100	
	City of Corona	ARV-13-XXX	18	
	Southern California Public Power Authority	ARV-13-XXX	4	9
	CALSTART, Inc.	ARV-13-XXX	38	
	Los Angeles County Metropolitan Transportation Authority	ARV-13-XXX	20	
	City of Torrance	ARV-13-XXX		6
	American Honda Motor Company, Inc.	ARV-13-XXX	116	
	US Hybrid Corporation	ARV-13-XXX	2	1
	Ontario CNG Station Inc	ARV-13-XXX		2
	Clean Fuel Connection, Inc.	ARV-13-022	34	
	Bio-Rad Laboratories, Inc.	ARV-13-023	3	
	Adopt A Charger	ARV-13-022	8	
	State of California, Department of Transportation (Caltrans)	ARV-13-XXX	13	
	General Distribution	various	678	4
	TOTAL		1,572	43
San Diego				
	Electric Transportation Engineering Corporation (ETEC) Corp. - Nissan	ARV-09-005 (ARRA match)	800	30
	Alternative Energy Systems Consulting, Inc.	ARV-12-013	10	-
	Alternative Energy Systems Consulting, Inc.	ARV-12-020	16	-
	ChargePoint, Inc.	ARV-12-024	206	-
	Alternative Energy Systems Consulting, Inc.	ARV-12-027	-	3
	City of San Diego	ARV-13-XXX	41	
	County of San Diego	ARV-13-XXX	35	
	City of Coronado	ARV-13-XXX	10	
	International Association of Nanotech (dba) US Green Vehicle Council	ARV-13-XXX		3
	State of California, Department of Transportation (Caltrans)	ARV-13-XXX	2	
	General Distribution	various	142	1
	TOTAL		1,262	37
North Coast				
	OurEvolution Energy & Engineering	ARV-12-012	2	-
Yucaipa				
	City of Yucaipa	ARV-12-030	8	-
Santa Barbara				
	Towbes Group Inc.	ARV-12-036	6	-
Reedley				
	City of Reedley	ARV-10-004	5	-
TOTAL			2,918	75

Table 16: Generally Distributed EVSE Stations

City or Urban Area	Recipient	Agreement Number	L2 Public EVSE	DC Fast Chargers
General Distribution	Coulomb Technologies	ARV-09-007 (ARRA match)	300	-
	Clipper Creek	ARV-10-001	822	-
	AeroVironment, Inc.	ARV-12-016	4	-
	AeroVironment, Inc.	ARV-12-017	4	-
	Joe Carlson Studio, Inc.	ARV-12-019	2	-
	Schneider Electric USA, Inc.	ARV-12-039	10	-
	Green Charge Networks, LLC	ARV-12-052	-	7
TOTAL			1,142	7

Table 17: Allocation of Generally Distributed EVSE Stations Across Four Metro Regions

City or Urban Area	2012 Census Urban Area Population	Percent of Total	L2 Public EVSE	DC Fast Chargers
Sacramento	1,723,634	7%	83	1
Bay Area	4,945,708	21%	238	1
LA Basin	14,083,662	59%	678	4
San Diego	2,956,746	12%	142	1
TOTAL	**23,709,750**	**100%**	**1,142**	**7**

Notes: "Bay Area" includes the following Urban Areas: San Francisco-Oakland; San Jose. "L.A. Basin" includes the following urban areas: Los Angeles-Long Beach-Anaheim; Riverside-San Bernardino.

Table 18: Assumed Average Gasoline Refills per Station and Maximum Charges per EVSE Station

	Refills or Max. Charges per Station per Day (RF)			
City	Gasoline ICE	L2 Public (PHEV)	L2 Public (BEV)	FC Station (BEV)
Los Angeles	443	27	30	59
Bay Area	377	27	30	59
San Diego	461	27	30	59
Sacramento	467	27	30	59

Figure 26: Vehicle Purchase Price Equivalent Benefit to Consumers due to the Service Rate Associated With L2 and Fast Charge EVSE Stations

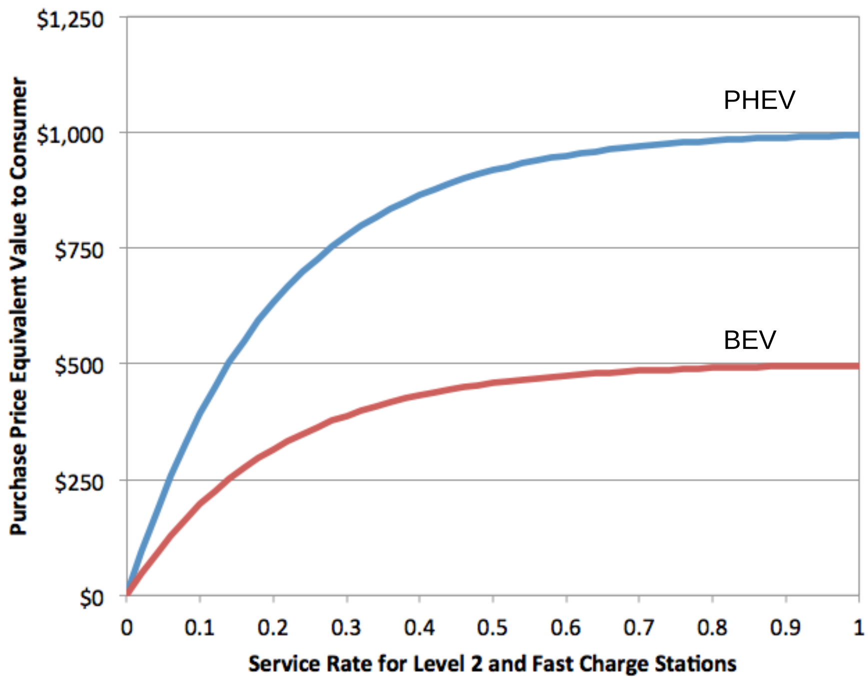


Table 19: Input Assumptions and Parameters in Determining the Change in PHEV, BEV, and FCEV Demand due to Increase in Fueling Availability

Case	Price Change	Demand Elasticity	P-Incumbent	P-New LDV	Price Slope
PHEVs			*HEV*	*PHEV (wCVRP)*	
Expected	-144	-5	$34,213	$38,513	-0.00016
Low	-72	-5	$34,213	$38,513	-0.00016
High	-216	-7	$34,213	$38,513	-0.00023
BEVs			*HEV CAR*	*BEV CAR (wCVRP)*	
Expected	-154	-5	$30,728	$38,602	-0.00016
Low	0	-5	$30,728	$38,602	-0.00016
High	-309	-7	$30,728	$38,602	-0.00022
FCEVs (2010 NOPA)	*11 new stations*		*HEV*	*FCEV (wCVRP)*	
High	-$500	-7	$34,213	$47,500	-0.00019
Low	-$500	-5	$34,213	$62,500	-0.00013
FCEVs (2013 NOPA)	*7 new stations*		*HEV*	*FCEV (wCVRP)*	
High	-$242	-7	$34,213	$47,500	-0.00019
Low	-$242	-5	$34,213	$62,500	-0.00013

Figure 27: Perceived Vehicle Price Reductions Over Years

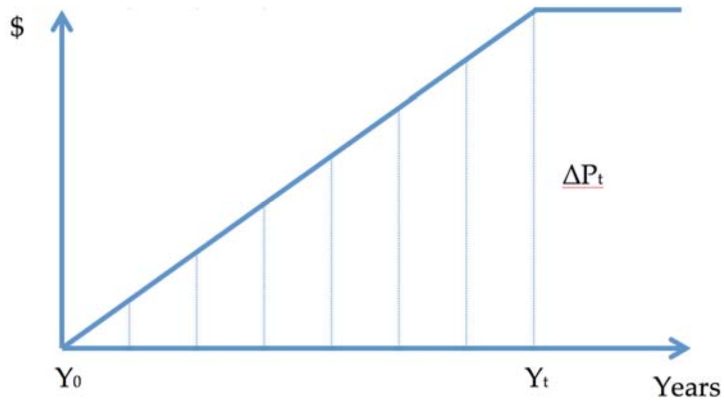


Table 20: Parameters Used in the Equation for the Value of Public EVSE Stations to PEVs

Urban Area	Gasoline Stations	Level 2 Public chargers		DC FC Stations	
		Before ARFVTP	After ARFVTP	Before ARFVTP	After ARFVTP
Los Angeles	2813	135	1,707	3	42
Bay Area	1164	395	1,181	13	49
San Diego	599	107	1,370	1	38
Sacramento	378	80	225	1	4
Total	4954	717	4484	18	133

Table 21: Vehicle Purchase Price Equivalent Benefit to Consumers for Increased EVSE Availability by Urban Area

Urban Area	Benefit of EVSE Availability (Before and After ARFVTP)				Change in the Benefit of EVSE Availability due to ARFVTP					
	PHEV		BEV		Expected Value		Minimum Value		Maximum Value	
	Before ARFVTP	After ARFVTP	Before ARFVTP	After ARFVTP	PHEV	BEV	PHEV	BEV	PHEV	BEV
Los Angeles	$14	$166	$8	$96	$152	$88	$76	$0	$307	$235
Bay Area	$113	$301	$66	$176	$188	$109	$94	$0	$360	$274
San Diego	$50	$483	$28	$270	$433	$242	$216	$0	$800	$585
Sacramento	$58	$156	$33	$89	$97	$55	$49	$0	$195	$147

Note: Minimum benefit results assume B*V values of $500 for PHEVs and $0 for BEVs, and maximum benefit results assume B*V values of $1500 for PHEVs and $1000 for BEVs (uniform distributions suggest from NRC 2013 study)

Figure 28: Additional PHEVs and BEVs Deployed due to an Increase in Public EVSE Stations

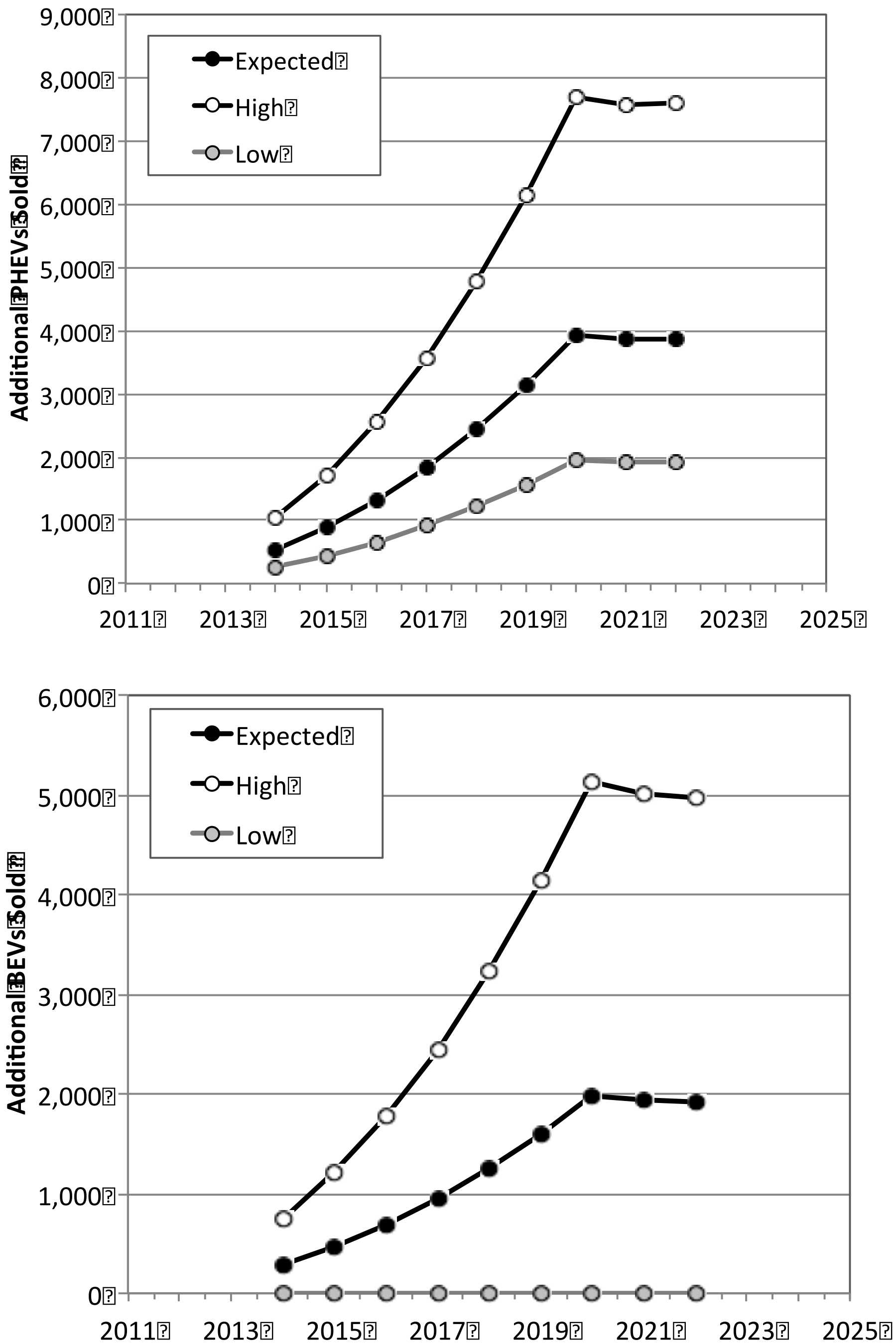


Figure 29: GHG Reductions From Additional PHEVs and BEVs Deployed due to an Increase in EVSE Availability

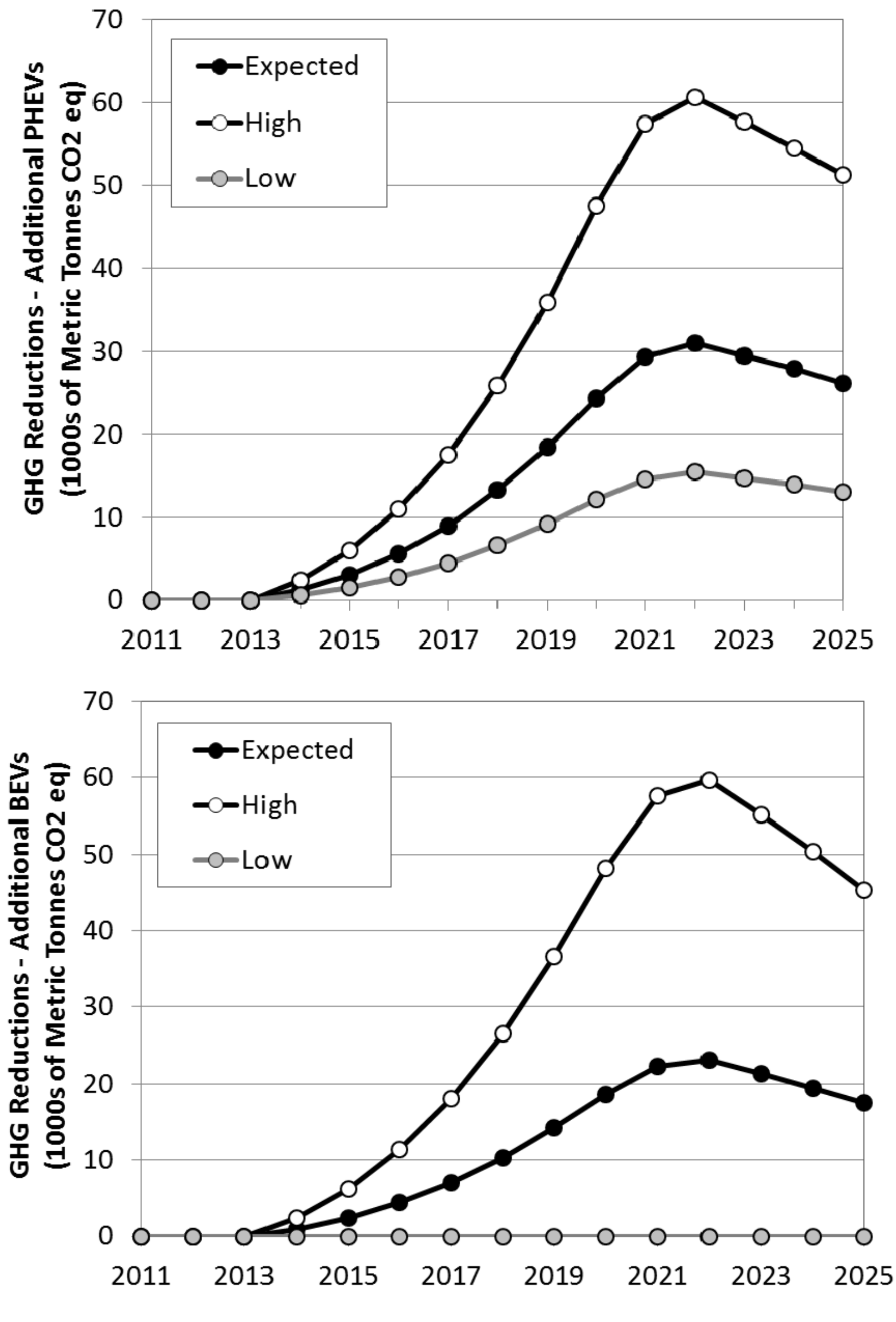
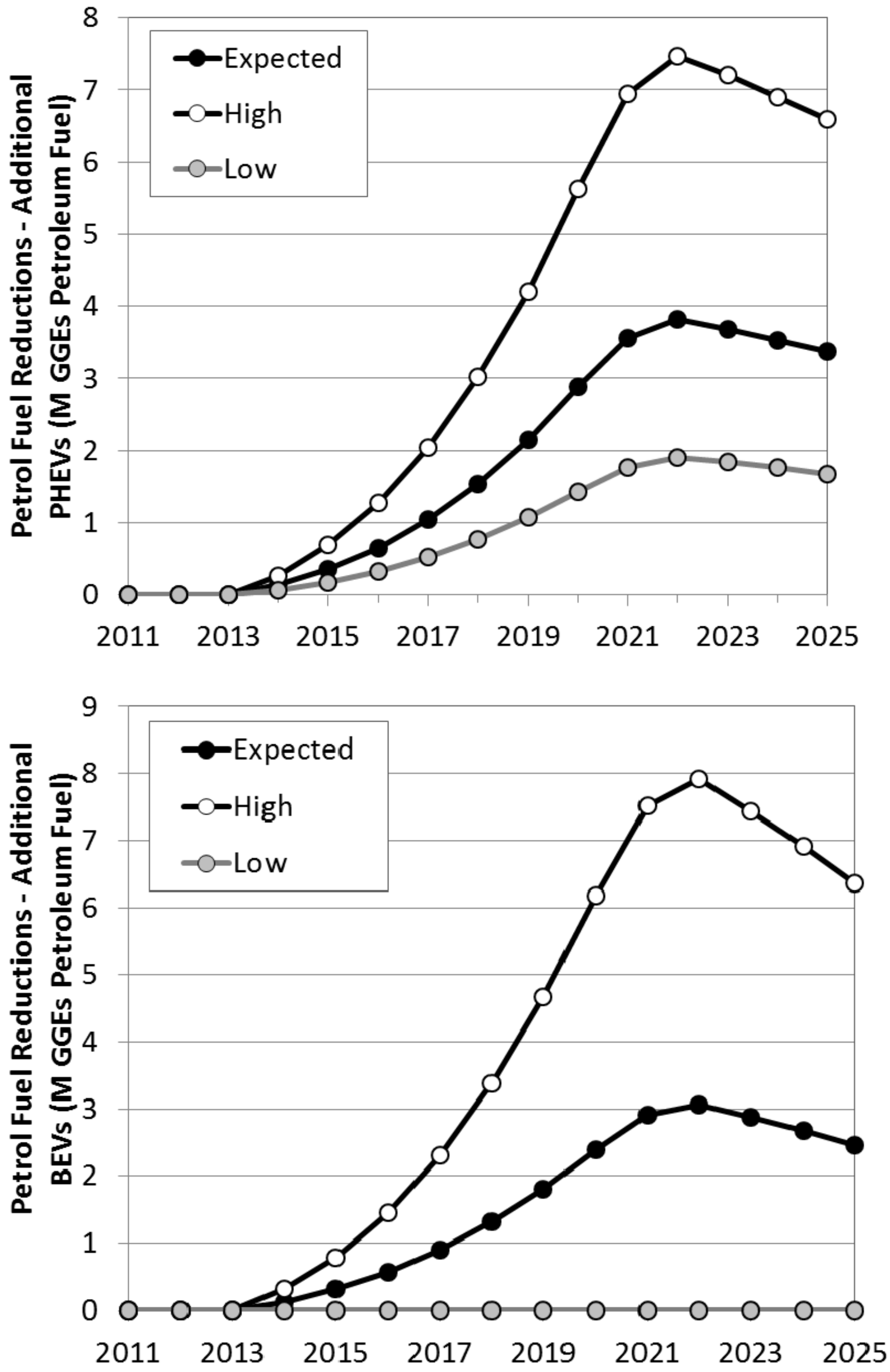


Figure 30: Petroleum Fuel Reductions From Additional PHEVs and BEVs Deployed due to an Increase in EVSE Availability



3.3.2 Increased Availability of Hydrogen Refueling Stations (HRS)

Several studies have attempted to estimate the number of HRS required to support early markets, and the California Fuel Cell Partnership (CaFCP) has developed a roadmap outlining required stations as early markets develop in the 2017 to 2019 time frame.[57,58,59,60] A limited number of studies have attempted to quantify the influence of limited availability on consumer behavior as a penalty against the purchase price of a new vehicle (Tompkins et al. 1998; Greene 1998; Melaina et al. 2012). More recent studies have assessed this influence in the context of an integrated consumer choice model that simulates competition among multiple types of advanced LDVs (NRC 2013; Greene et al. 2013). In theory, if HRS availability is expressed as a percentage of existing gasoline stations in a given area, the cost penalty should approach infinity as the percentage approaches zero. Unlike PEVs or CNGVs, which can be refueled at home, the large majority of FCEVs will be fueled from public HRS located near early adopter households or along major travel corridors. As the availability of HRS increases in a given urban area or region, this cost barrier will be reduced, and consumers will perceive FCEVs as having a greater utility. Though additional research is needed in this area, and important market data will be collected as early FCEVs are introduced, results from existing consumer choice studies can be relied upon to estimate the degree to which this vehicle purchase price penalty is reduced as additional HRS are installed in a given area.

This analysis relies upon results from a series of discrete choice surveys conducted between 2007 and 2009 for multiple major urban areas (Melaina et al. 2012). The cost penalties suggested in this study are similar in magnitude and functional form as those used in other studies (NRC 2013; Greene et al. 2013), but are distinct from other estimates in that they can be tailored to specific urban areas or regional infrastructure development patterns. The results can be tailored to specific urban areas because variations in cost penalty results are reported for multiple urban areas, capturing variations due to metrics such as urban area population and gasoline station availability (such as urban stations per square mile). Figure 31 indicates general results for four major urban areas, with natural log function fits to logit model results from the survey data. The natural log equations indicated in the figure reflect cost penalty trends when very few stations are available, near 1-5 percent of conventional stations (horizontal axis). The exponential

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57 Melaina, M. W. (2002). “Initiating hydrogen infrastructures: preliminary analysis of a sufficient number of initial hydrogen stations in the U.S.” Presented at the Market Challenges of Fuel Cell Commercialization, Berlin, Sorat Hotel, Spree Bogen, September 12, 2002, *International Journal Hydrogen Energy* (Vol. 28, Issue 7).

58 Nicholas, M. A., S. L. Handy and D. Sperling (2004). "Using Geographic Information Systems to Evaluate Siting and Networks of Hydrogen Stations." *Transportation Research Record* 1880: 126-134.

59 Stephens-Romero, S. D., T. M. Brown, J. E. Kang, W. W. Recker and G. S. Samuelsen (2010). "Systematic planning to optimize investments in hydrogen infrastructure deployment." *International Journal of Hydrogen Energy* 35(10): 4652-4667.

60 CaFCP (2012). *A California Road Map: The Commercialization of Hydrogen Fuel Cell Vehicles.* Sacramento, California, California Fuel Cell Partnership, http://cafcp.org/carsandbuses/caroadmap

functions presented in Melaina et al. (2012), not shown in Figure 31, provide a more consistent representation of cost penalties in the 5-25 percent availability range, though both functional forms capture the general trend. Given the limited number of existing HRS in the four major California urban areas, the natural log equations are deemed a more appropriate functional form. As indicated, the natural log functions suggest penalties in the $2,000-$5,000 range at station availabilities less than 2-3 percent. This functional form of the cost penalty is therefore relatively conservative for estimating ARFVTP benefits: a steeper cost function at low availability would suggest a more rapid reduction in the cost penalty and, therefore, greater market impact for the installation of early stations. As is the case for EVSE availability and PEV market adoption trends, analytic representations of how consumers value public refueling will improve as empirical data are collected during early market deployments.

The "Cluster (All)" cost penalty trend indicated in Figure 31 is distinct from the other city-specific cost penalty trends. The cluster algorithm penalty is based upon travel time simulations and a nuisance cost associated with the additional time required to drive to a HRS when stations availability is limited. Tis cost penalty trend is lower than the other trends and reflects a lower-bound or "rational behavior" penalty that might occur if consumers had more complete knowledge of existing station locations in relation to their normal driving and refueling patterns. In contrast, the high cost penalties indicated, and relied upon for this analysis, are theoretical penalties based upon or stated preference results from a discrete choice survey that showed respondents maps of their urban area with different levels of station availability (for additional details, see Melaina et al. 2012). In general, stated preference penalties tend to be higher than those resulting from rational actor simulations. Actual penalties may approach those suggested by rational actor models as more stations are deployed and consumers have greater access to real-time information on local HRS availability.

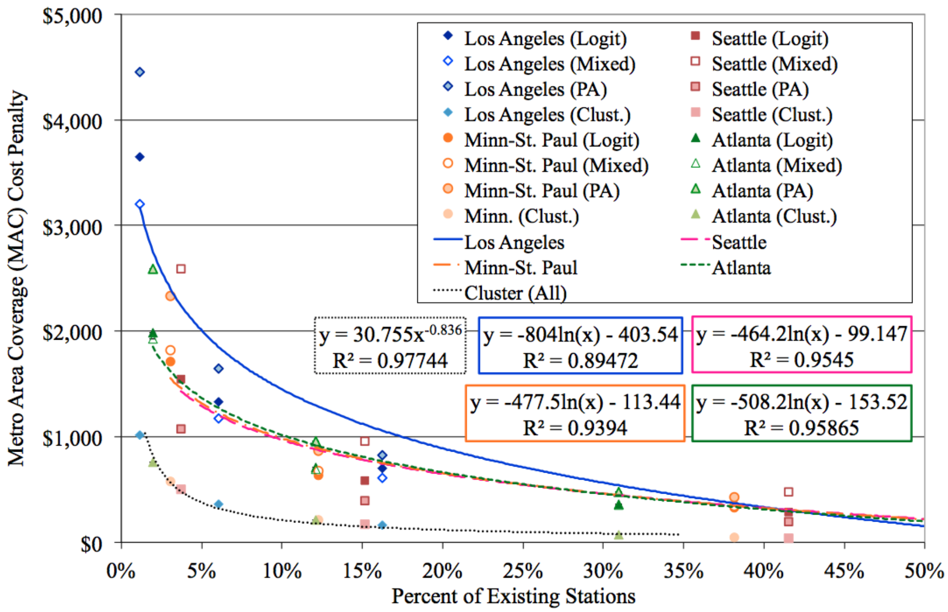
The coefficients for the natural log functions in Figure 31 correlate strongly with urban area population and, therefore, can be relied upon to estimate penalties for urban areas of different populations. As indicated, penalties are higher for Los Angeles (~16 million persons) than for Atlanta (~ 5 million persons). Both are higher than those for Minneapolis and Seattle (~3 million persons). This correlation has been used to estimate penalties for limited refueling availability in the San Francisco Bay Area (including San Francisco, the East Bay, and San Jose), San Diego, and Sacramento. Expected metro baseline cost penalties for each urban area are indicated in Table 22 for the eight public hydrogen refueling stations (HRS) installed before new stations from the ARFVTP had been installed. These initial penalties serve as a reference for penalty reductions resulting from the additional stations awarded to date according to the 2011, 2013, and 2014 Notice of Proposed Award (NOPA) documents from ARFVTP. These penalties are indicated with reference to the total number of conventional refueling stations in each urban area. For San Diego and Sacramento, with zero stations installed before ARFVTP, a baseline penalty is estimated using "0.1" stations as an input to the logarithmic penalty functions. As mentioned, this functional form is a conservative estimate at very low station availability, as in theory the penalty should approach infinity near zero stations. Given that these baseline percentages are very small in all four urban areas, it is the relative change in the cost penalty that is relevant for estimating the potential market impact of installing new HRS.

Given the functional form of the cost penalty curves in Figure 31, penalty reductions are greater for the first stations installed in a given urban area, even though these penalties are relatively conservative near negligible station availability (for example, fewer than 1 percent of stations). Given that automakers will likely not be offering FCEVs for sale in urban areas that lack stations, few early adopters will be subject to market conditions where station availability is near zero.

While Figure 31 reviews cost penalties associated with a lack of HRS availability in urban areas, the stated preference results in Melaina et al. (2012) suggest that significant penalties are also incurred due to a lack of availability for medium-distance trips within 150 miles of an urban center as well as for long-distance trips along interstates to other urban areas. Recent ARFVTP awards for connector and destination HRS outside urban areas contribute to reducing the latter of these two additional penalties. Figure 32 indicates cost penalties increasing with a greater percentage of long-distance trips along interstates not possible due to limited HRS availability along interstates. These stated preference results suggest relatively high penalties, near $1,000 to $4,000, for even very infrequent long-distance trips along interstates (for example, from West Coast urban areas to East Coast urban areas).

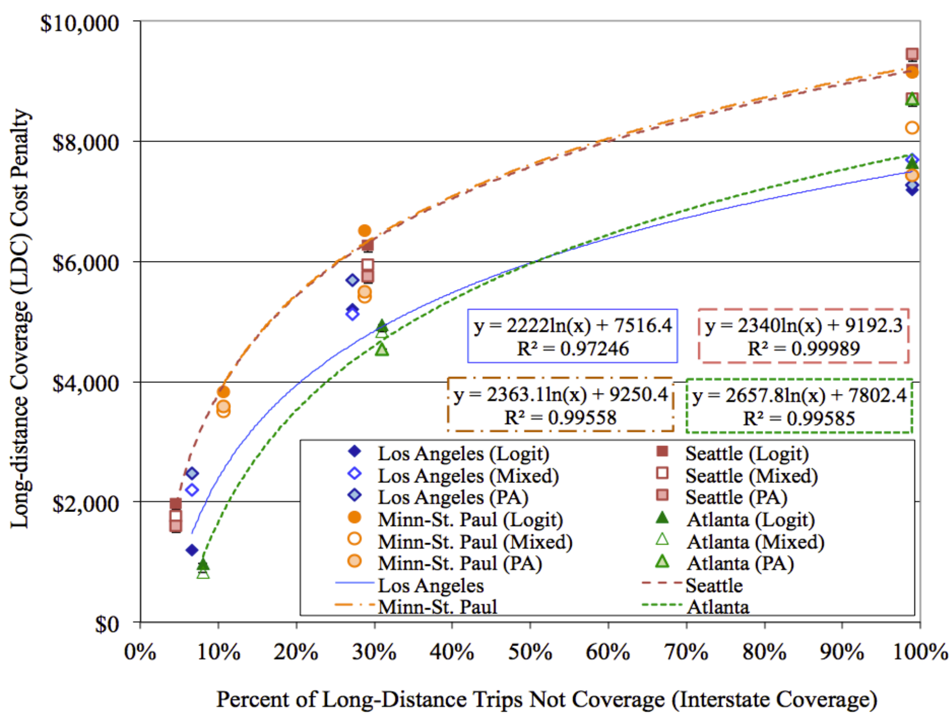
Given the early stages of providing HRS availability for long-distance interstate trips in California, a linear relationship is assumed with the initial penalty declining by $2,000 for the first six contiguous HRS located at roughly 150-mile intervals along interstates connecting an urban areas to other nearby urban areas. This reduction is comparable to the result indicated for Los Angeles declining from $7,000 to about $5,000 when only 30 percent of long-distance trips are not possible due to limited HRS availability. As indicated in Melaina et al. (2012), the 26 percent of long-distance trips availability level is associated with interstate trips to the San Francisco Bay Area, Las Vegas, and Phoenix, which might represent a reasonable long-distance availability expectation for early adopters. Adopting this $2,000 baseline penalty for interstate coverage, instead of a full $7,000 penalty, and waiving the penalty for medium-distance trips acknowledge that FCEV early adopters must have some tolerance for limited refueling availability, as must BEV early adopters have some tolerance for limited vehicle range. Interstate coverage penalties are shown as additive to metro coverage penalties, summing to $5,500 to $6,500 in total baseline penalties before ARVTP HRS are installed.

Figure 31: Cost Penalty Estimates Against the Purchase Price of a New Dedicated AFV for Limited Urban Area Station Availability for Both Survey Results and Cluster Simulations



Source: Melaina et al. (2012)

Figure 32: Cost Penalty Estimated for the Percentage of Long-Distance Trips Along Interstates Not Covered due to HRS Availability



Source: Melaina et al. (2012)

Table 22: Vehicle Purchase Price Cost Penalty Estimated for HRS Installations in Urban Areas

Urban Area	Reference Stations	Baseline Metro Penalty Before ARFVTP HRS	% Stns	Penalty	Interstate Penalty	Total 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 ARFVTP are nominal values shown to reflect penalties near zero availability.

Six HRS from the 2014 NOPA are considered as providing a benefit to early adopters against the interstate coverage penalties discussed above. These are listed in Table 22. As indicated, most of the stations help reduce interstate coverage penalties in more than one urban area. Installing stations at the Truckee and San Ramon station locations reduce interstate penalties for early adopters in the San Francisco Bay Area and Sacramento, the Santa Barbara station reduces interstate penalties for early adopters in Los Angeles and San Diego, and the Coalinga station reduces penalties for early adopters in all four urban areas. The Woodside and Rohnert Park stations are assumed to reduce interstate penalties only for early adopters in the Bay Area. Table 23 indicates the contribution toward the baseline $2,000 penalty, assuming a benefit of $333 per station applied linearly across all applicable stations. Given these assumptions, the Coalinga station provides the greatest reduction in interstate coverage penalties as a key connector station, and the Bay Area receives the greatest overall benefit from five stations. As discussed above, this is a relatively simple treatment of interstate coverage, extrapolating from the stated preference results for Los Angeles indicated in Figure 32, and could be improved upon with additional spatial travel demand and consumer preference analysis.

Table 23: Benefit of Connector and Destination HRS From the 2014 NOPA Against Interstate Coverage Penalties by Urban Area

Interstate Station	Metro Area: Los Angeles	Bay Area	San Diego	Sacramento
Coalinga	1	1	1	1
Truckee		1		1
San Ramon		1		1
Woodside		1		
Santa Barbara	1		1	
Rohnert Park		1		
Total	2	5	2	3
Benefit/Station	$333	$333	$333	$333
Total Benefit	$667	$1,667	$667	$1,000

Table 24 summarizes the benefits to consumers in each major urban area as reductions in HRS availability penalties for the 2011, 2013, and 2014 ARFVTP NOPAs. The table also indicates the resulting number of HRS awarded and the corresponding percentage of total gasoline stations. (Absolute values are shown in Table 22.) These values are shown cumulatively with each new NOPA, and the 2014 NOPA includes benefits associated with interstate penalty reductions. The final column in the table indicates the total penalty remaining for each urban area, which can be compared to the baseline penalties indicated in Table 22.

In theory, these cost penalty reductions apply for all consumers in a given urban area and, therefore, represent one of the strong network externalities discussed for early ZEV markets by Greene et al. (2013). To estimate market transformation benefits associated with reducing this market barrier, new FCEV sales are estimated for a limited consumer market segment, rather than for all new LDV purchasers in each urban area. This assumption is consistent with the nested logit market share framework discussed above and reflects an assumption that other market barriers exist due to the novelty of the technology, limiting initial new sales to a relatively small (and geographically confined) early adopter market. In other words, the market share calculation with reference to HRS availability is not an "all else being equal" calculation. This market segmentation assumption parallels the market segmentation assumption for BEVs resulting from an increase in public EVSE stations.

The depth of the early adopter market for FCEVs is highly uncertain. Moreover, the typical vehicle price expected for early FCEVs is also uncertain. In an effort to capture the range of potential market impacts associated with these uncertainties, changes in market share due to increased HRS availability are estimated for two early adopter market segments (2.5 percent and 10 percent of LDV sales) and two vehicle price points ($65,000 and $50,000). This range reflects the difference between two possible future market trends: (1) early FCEVs are introduced at a relatively high average price point for a targeted early adopter market segment, and (2) early FCEVs are introduced at a slightly lower average price point for a broader early adopter market segment. In both cases some FCEV makes and models may be introduced with prices higher or lower than these average values. This vehicle price range is comparable, but not equal, to price trends reported in the 2013 NRC study. As suggested in the earlier discussion of the cost reductions due to experience and corresponding pricing strategies that might be adopted, different original equipment manufacturers (OEMs) may choose different pricing and marketing strategies. The range of price points and market segments assumed here reflects what might be a collective market outcome of many OEMs offering FCEVs during the early market introduction phase, acknowledging that some variation is likely.

Another important uncertainty is the premium early adopters might place on FCEVs due to inherent attributes such as "greenness" or high-tech appeal. While no explicit value is used to estimate this premium within the discrete choice framework, the assumption that some HRS coverage penalties are lower than the mass-market stated preference results from Melaina et al. (2012) may be interpreted as an early adopter premium. When FCEVs begin to be deployed, additional data will be collected on consumer preferences and the value placed on refueling availability relative to other vehicle attributes. As is the case for PEV markets and public EVSE availability, the collection of empirical data as market shares increase will improve the analytic capability to quantify the role and relative influence of station availability as a market barrier.

Table 24: Benefits Against HRS Availability Penalties for Three ARFVTP NOPAs

Urban Area	With 2010 NOPA (PON-09-608)			With 2013 NOPA (PON-12-606)			With 2014 NOPA (PON-13-607)					Remaining
	HRS	% Stns	Benefit	HRS	% Stns	Benefit	HRS	% Stns	Metro	Interstate	Total	Penalty
Los Angeles	16	0.6%	$665	20	0.7%	$844	32	1.1%	$1,222	$667	$1,889	$4,529
Bay Area	2	0.2%	$376	5	0.4%	$873	14	1.2%	$1,431	$1,667	$3,097	$2,556
San Diego	0	0.0%	$0	0	0.0%	$0	1	0.2%	$1,066	$667	$1,733	$4,191
Sacramento	1	0.3%	$1,000	1	0.3%	$1,000	1	0.3%	$1,000	$1,000	$2,000	$3,499
Total	19	0.4%		26	0.5%		48	1.0%				

The market share calculations assume that the vehicle rebate of $2,500 per vehicle for BEVs is also made available to FCEVs, and that FCEVs compete against an incumbent vehicle at a price point equivalent to an HEV, as indicated in Table 19. The resulting high and low estimates for increased FCEV sales due to the 2011 NOPA stations, the sum of the 2011 and 2013 NOPA stations, and the combined influence of the 2011, 2013, and 2014 NOPA stations are indicated in Figure 33. Additional FCEV sales in the high case (10 percent market segment and $50,000 per vehicle) range between 500 to 8,000 additional sales per year, and sales in the low case (2.5 percent market segment and $65,000 per vehicle) are estimated to range from 200 to 2,500 additional sales per year. In sum, based upon this analytic framework, the additional 40 stations supported to date through ARFVTP awards would have a significant effect on sales if FCEVs are introduced at a relatively low price point and a broad market segment, and a more modest effect if they are introduced at a higher price point and narrower market segment. This result reflects the strong coupling between early HRS deployments required to increase station availability and the pricing and marketing strategies adopted by OEMs during the early market growth phase. The GHG emission and petroleum fuel reductions resulting from these additional FCEV sales are indicated in Figures 34 and 35.

While these market transformation benefits are considered additive to the expected benefits associated with station capacity in Chapter 2, total benefits associated with ARFVTP support for FCEV markets are limited by the market share growth rate. Growth in FCEV market share depends upon continued ARFVTP support to a greater degree than growth in PHEV or BEV market share, and, therefore, a greater portion of future market growth benefits is arguably attributable to ARFVTP support. This analysis attempts to estimate these future benefits based upon HRS deployment efforts supported to date.

Figure 33: Additional FCEVs Sold Due to Installation of Hydrogen Refueling Stations (HRS)

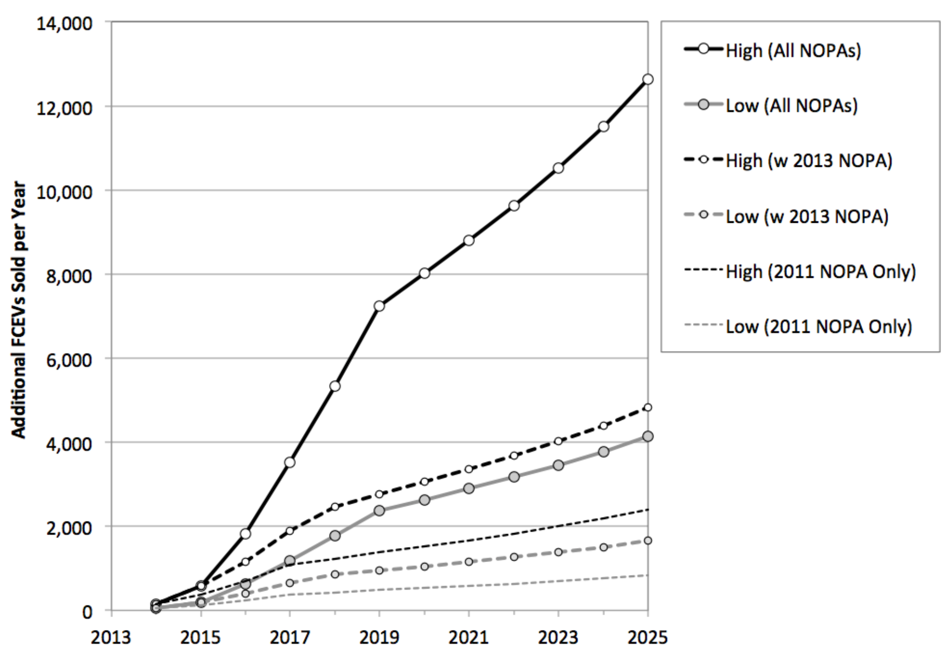


Figure 34: GHG Reductions From Additional FCEVs due to Increased HRS Availability

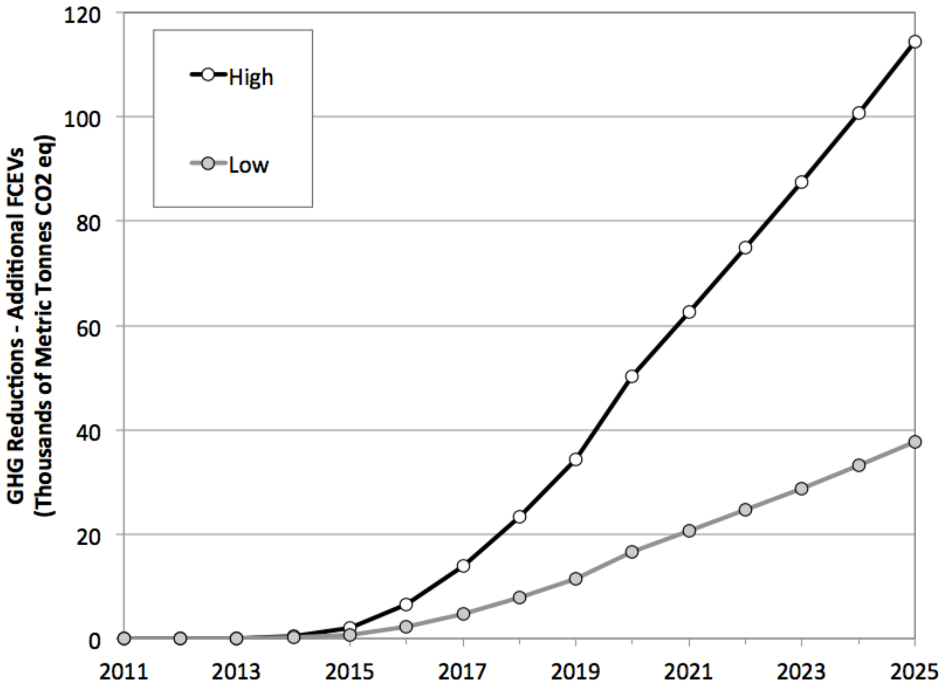


Figure 35: Petroleum Fuel Reductions From Additional FCEVs due to Increased HRS Availability

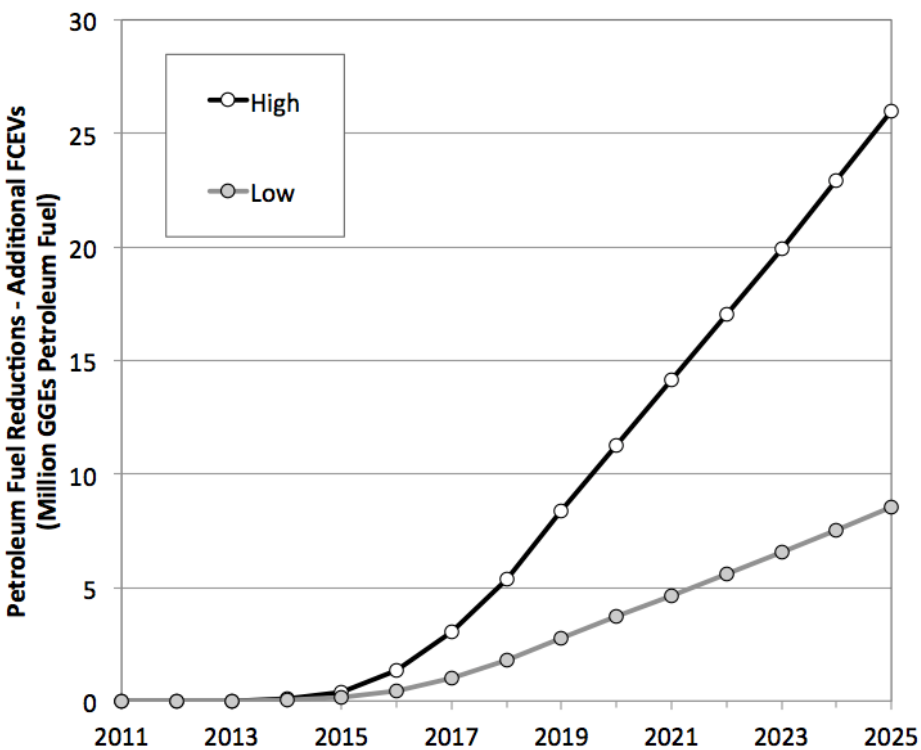


Table 25: Air Pollutant Emission Reductions due to Increased EVSE and HRS Availability

Technology and Case		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Additional VMT (billions)														
BEVs	Expected	-	0.00	0.01	0.02	0.03	0.05	0.07	0.09	0.11	0.12	0.11	0.11	0.10
	High	-	0.01	0.03	0.05	0.08	0.12	0.18	0.24	0.30	0.31	0.29	0.27	0.25
	Low	-	-	-	-	-	-	-	-	-	-	-	-	-
PHEVs	Expected	-	0.01	0.02	0.04	0.06	0.09	0.13	0.18	0.23	0.25	0.24	0.22	0.21
	High	-	0.01	0.04	0.07	0.12	0.18	0.26	0.36	0.45	0.48	0.46	0.44	0.42
	Low	-	0.00	0.01	0.02	0.03	0.05	0.07	0.09	0.11	0.12	0.12	0.11	0.11
FCEVs	High	-	0.00	0.01	0.05	0.11	0.19	0.31	0.43	0.56	0.69	0.82	0.97	1.12
	Low	-	0.00	0.00	0.02	0.04	0.07	0.10	0.14	0.18	0.23	0.27	0.32	0.37
TOTAL	High	-	0.03	0.08	0.17	0.31	0.50	0.75	1.03	1.30	1.48	1.58	1.68	1.79
	Low	-	0.00	0.01	0.03	0.07	0.11	0.17	0.23	0.30	0.35	0.39	0.43	0.48
ROG Emission Reductions (tonnes)														
BEVs	Expected	-	0.2	0.6	1.1	1.8	2.6	3.7	5.1	6.3	6.7	6.3	5.8	5.3
	High	-	0.6	1.5	2.8	4.5	6.8	9.7	13.1	16.2	17.3	16.2	15.0	13.8
	Low	-	-	-	-	-	-	-	-	-	-	-	-	-
PHEVs	Expected	-	0.3	0.9	1.7	2.7	4.2	6.0	8.2	10.3	11.1	10.6	10.1	9.6
	High	-	0.7	1.7	3.2	5.4	8.2	11.7	16.1	20.2	21.8	20.8	19.8	18.7
	Low	-	0.2	0.4	0.8	1.4	2.1	3.0	4.1	5.2	5.5	5.3	5.0	4.8
FCEVs	High	-	0.2	0.7	2.5	5.8	10.7	17.1	23.7	30.6	37.8	45.3	53.3	61.8
	Low	-	0.1	0.3	0.9	2.0	3.6	5.7	7.9	10.1	12.5	14.9	17.5	20.3
TOTAL	High	-	0.7	2.2	5.2	10.3	17.5	26.9	37.0	47.2	55.6	62.2	69.2	76.7
	Low	-	0.2	0.7	1.7	3.3	5.7	8.7	12.0	15.3	18.0	20.2	22.6	25.1
NOx Emission Reductions (tonnes)														
BEVs	Expected	-	0.3	0.7	1.4	2.2	3.4	4.8	6.5	8.0	8.5	8.0	7.4	6.8
	High	-	0.7	1.9	3.5	5.8	8.7	12.3	16.7	20.7	22.0	20.6	19.2	17.6
	Low	-	-	-	-	-	-	-	-	-	-	-	-	-
PHEVs	Expected	-	0.4	1.0	1.8	3.0	4.6	6.7	9.1	11.5	12.4	11.8	11.2	10.6
	High	-	0.7	1.9	3.6	6.0	9.1	13.0	17.9	22.4	24.2	23.1	22.0	20.8
	Low	-	0.2	0.5	0.9	1.5	2.3	3.3	4.6	5.7	6.2	5.9	5.6	5.3
FCEVs	High	-	0.2	0.9	3.2	7.4	13.6	21.8	30.2	39.0	48.1	57.7	67.9	78.7
	Low	-	0.1	0.3	1.1	2.5	4.6	7.2	10.0	12.9	15.8	19.0	22.3	25.8
TOTAL	High	-	2.0	5.4	11.7	21.5	34.9	52.3	71.9	91.1	103	110	117	125
	Low	-	0.3	1.0	2.4	4.6	7.8	11.9	16.4	20.9	24.5	27.2	30.1	33.3
PM2.5 (Total) Emission Reductions (tonnes)														
BEVs	Expected	-	0.0	0.1	0.2	0.3	0.4	0.6	0.8	1.0	1.1	1.0	1.0	0.9
	High	-	0.1	0.2	0.5	0.7	1.1	1.6	2.1	2.7	2.8	2.7	2.5	2.3
	Low	-	-	-	-	-	-	-	-	-	-	-	-	-
PHEVs	Expected	-	-	-	-	-	-	-	-	-	-	-	-	-
	High	-	-	-	-	-	-	-	-	-	-	-	-	-
	Low	-	-	-	-	-	-	-	-	-	-	-	-	-
FCEVs	High	-	0.0	0.1	0.4	1.0	1.7	2.8	3.9	5.0	6.2	7.4	8.7	10.1
	Low	-	0.0	0.0	0.1	0.3	0.6	0.9	1.3	1.7	2.0	2.4	2.9	3.3
TOTAL	High	-	0.1	0.2	0.6	1.2	2.2	3.4	4.7	6.0	7.3	8.4	9.7	11.0
	Low	-	0.0	0.0	0.1	0.3	0.6	0.9	1.3	1.7	2.0	2.4	2.9	3.3
CO Emission Reductions (1000 tonnes)														
BEVs	Expected	-	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.3	0.2	0.2	0.2
	High	-	0.0	0.1	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.6	0.6	0.5
	Low	-	-	-	-	-	-	-	-	-	-	-	-	-
PHEVs	Expected	-	0.0	0.0	0.0	0.1	0.1	0.1	0.2	0.3	0.3	0.3	0.2	0.2
	High	-	0.0	0.0	0.1	0.1	0.2	0.3	0.4	0.5	0.5	0.5	0.5	0.5
	Low	-	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.1	0.1
FCEVs	High	-	0.0	0.0	0.1	0.2	0.4	0.7	0.9	1.2	1.4	1.7	2.0	2.4
	Low	-	0.0	0.0	0.0	0.1	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8
TOTAL	High	-	0.0	0.1	0.2	0.4	0.6	0.9	1.3	1.7	2.0	2.2	2.5	2.8
	Low	-	0.0	0.0	0.1	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9

3.4 Influence of Investments in Vehicle Production

The benefits associated with ARFVTP investments in electric-drive vehicle production are estimated based upon an increase in market share due to a projected reduction in future vehicle prices. A range of future prices changes is estimated based upon applying an average industry experience curve and varying the progress ratio to determine high and low estimates. However, rather than assuming that all ARFVTP and increased profit margins associated with cost reductions are passed on to consumers, the research team assumes that only a fraction is passed on as consumer surplus. The result is an estimate of the degree to which aggregate industry learning or experience can reduce future costs, assuming that market prices also decline, resulting in increased market share for electric-drive vehicles. This same framework is applied to investments in both manufacturing processes and vehicle components. The research team assumes that these production cost reductions are realized only in PHEVs and BEVs and do not extend to FCEVs. More detailed analysis of cost reductions achieved at the vehicle component level would be required to estimate spillover effects into fuel cell vehicle drivetrain production costs.

The general function for a change in production cost, or price in this case as the research team assumes the markup cost to be constant, is:

$$P_1 = P_o * \left(\frac{Q1}{Q0}\right)^{-b}$$

Where,

P_1 = Vehicle price as a function of cumulative volume ($/vehicle)
P_0 = Vehicle price before increase in volume ($/vehicle)
Q_0 = Cumulative vehicles produced before the increased output (number vehicles)
Q_1 = Cumulative vehicles produced after the increased output (number vehicles
b = learning factor.

Cost reductions due to increased experience are often described in terms of a progress ratio (*PR*), which can be calculated based upon the learning factor, b, and represent the percentage of initial cost remaining after a doubling in the cumulative production level (P_1/P_o). For example, a *PR* of 90 percent indicates a 10 percent reduction in unit costs after a doubling of cumulative production. Setting Q_0 equal to $2Q_1$ in the equation above, *PR* can be calculated as being equal to 2^{-b}. The research team assumes an aggregate industry progress ratio (*PR*) of 0.95, with a high of 0.912 and a low of 0.988, following cost trends from the NRC 2013 study. There is a significant literature on the development of experience curves and the use of these experience curves for informing technology policy.

As shown in Figure 36, supplying additional funds to the production of electric-drive vehicles would result in a shift in the supply curve to the right, with the result that consumers pay price P_1 at the new cumulative output volume Q_1. The area P_0P_1BA is the increase in consumer surplus due to the price drop. However, due to the additional funding provided, producers receive price P_s at Q_1, with total funds represented by area P_sP_1BC. Assuming that mark-up factors are constant, the research team calculates the price P_1 as presented in Equation 2.

The research team further assumes that consumers would gain 60 percent of the additional funds as consumer surplus, and producers 40 percent as producer surplus. Because of the deadweight loss (DWL), area ABC, consumers would actually benefit somewhat less than the total consumer surplus, with area P_0P_1BA being less than area P_0P_1BE. Next, the research team can calculate the change in vehicle sales as Q_1 minus Q_0 using the following equation:

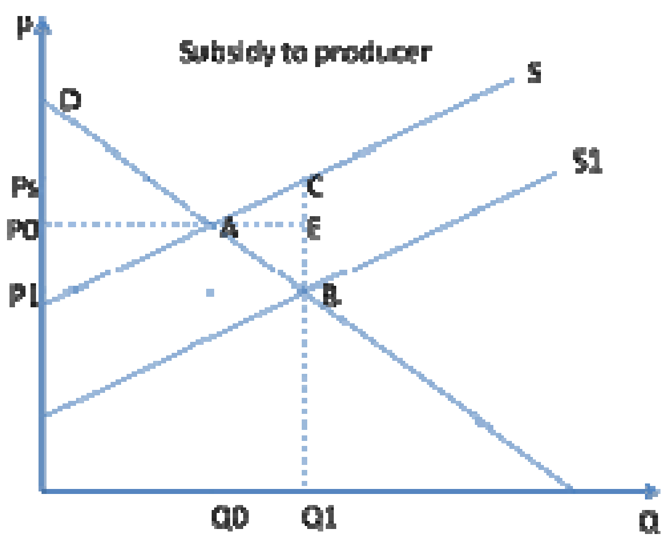
$$P_o * \left[1 - \left(\frac{Q_o+\Delta Q}{Q_o}\right)^{-b}\right] * (Q_o + \Delta Q) = A * 60\% \mathrm{P_o} * \left[1 - \left(\frac{\mathrm{Q_o}+\Delta \mathrm{Q}}{\mathrm{Q_o}}\right)^{-\mathrm{b}}\right] * (\mathrm{Q_o} + \Delta \mathrm{Q}) = \mathrm{A}*60\% \quad (3)$$

where,

A = Total investment amount (dollars)
ΔQ = Change in price ($P_o - P_1$)

These two analytic formulations provide alternate means of estimating a change in price based upon a specified investment (A), a learning factor (b), an initial cumulative production output (Q_0), and an initial vehicle price (P_o). The change in vehicle price is applied in addition to the CVRP rebate to determine the change in market share for both manufacturing and component investments.

Figure 36: Economic Allocation to Producers and Consumers



3.4.1 Reductions due to Investments in Electric Drive Vehicle Production Processes

The metrics used to determine market share changes due to investments in component production and manufacturing processes are summarized in Table 26. The resulting change in vehicle price is assumed to persist through 2025 in both cases. Results are relatively sensitive to the initial production volume, which is estimated as 100,000 electric drive vehicles to reflect the recent surge in vehicle production activity. The research team does not claim that this as an accurate representation of the global ZEV market, given that significant data gaps exist on both private investments to date and advances in reducing costs associated with specific components, such as batteries, and how these components are used to what degree in the different types of BEVs and PHEVs being deployed. The results shown here are assumed to apply to the California market, and the 100,000 cumulative production estimate is a rough approximation of cumulative sales over the last several years for major ZEV makes and models.[61,62]

The additional PEVs adopted due to price reductions resulting from investments in electric drive component production and manufacturing are shown in Figures 37 and 38. The numbers of PHEVs and BEVs adopted are very similar in both the high and low cases. The GHG and petroleum fuel reductions associated with these additional PEVs are shown for component production investments in Figure 39 and for manufacturing processes in Figure 40. Criteria emission reductions from additional PEV deployments are summarized in Table 27.

Table 26: Metrics and Results From Increased Vehicle Production Experience

Project Category	Case	Progress Ratio (PR)	Initial Production Volume (Qo)	Invested ($M)	Consumer Surplus (%)	Price Change (%)	BEV Market Share Increase (%)	PHEV Market Share Increase (%)
Component Production	High	0.912	100,000	$29.4	60%	0.37%	0.40%	0.52%
	Low	0.988	100,000	$29.4	60%	0.32%	0.34%	0.44%
Manufacturing Processes	High	0.912	100,000	$28.1	60%	0.24%	0.26%	0.34%
	Low	0.988	100,000	$28.1	60%	0.22%	0.23%	0.30%

61 "October 2013 Dashboard," *HybridCars*, Accessed Nov. 1, 2013, at: http://www.hybridcars.com/october-2013-dashboard.

62 "Sales Stats," *Good Car Bad Car*, Accessed Nov. 1, 2013, at: http://www.goodcarbadcar.net/2011/01/chevrolet-volt-sales-figures.html.

Figure 37: Additional PEVs Adopted due to Investments in Component Production

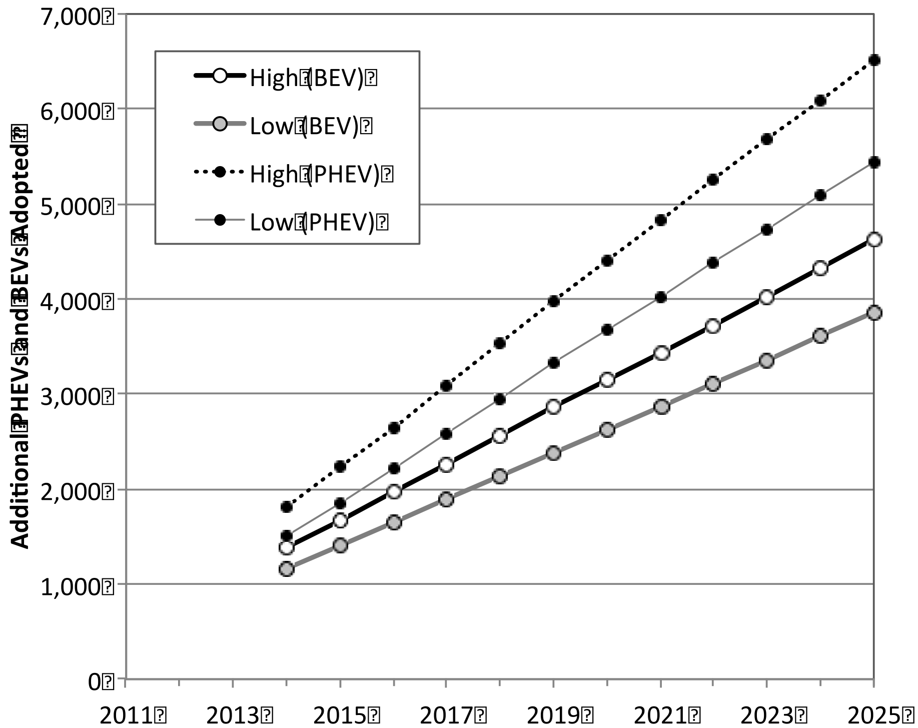


Figure 38: Additional PEVs Adopted due to Investments in Manufacturing

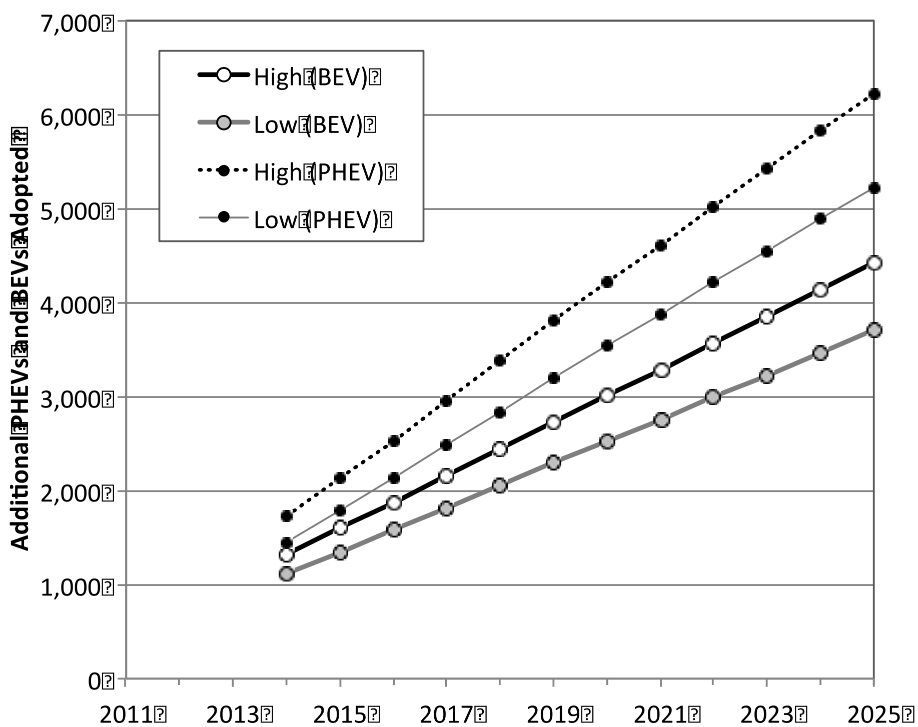


Figure 39: GHG and Petroleum Fuel Reductions from Investments in Component Production

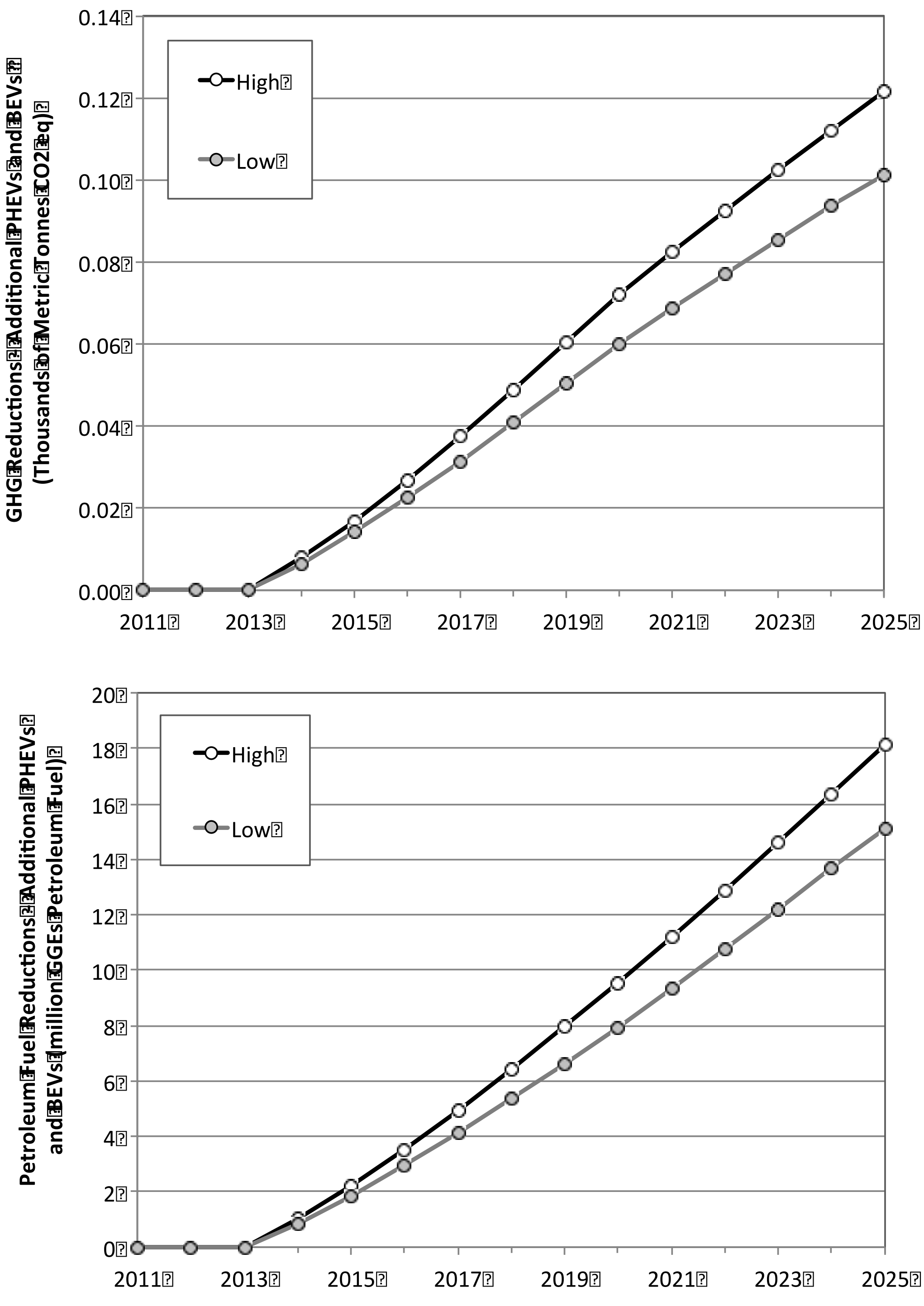
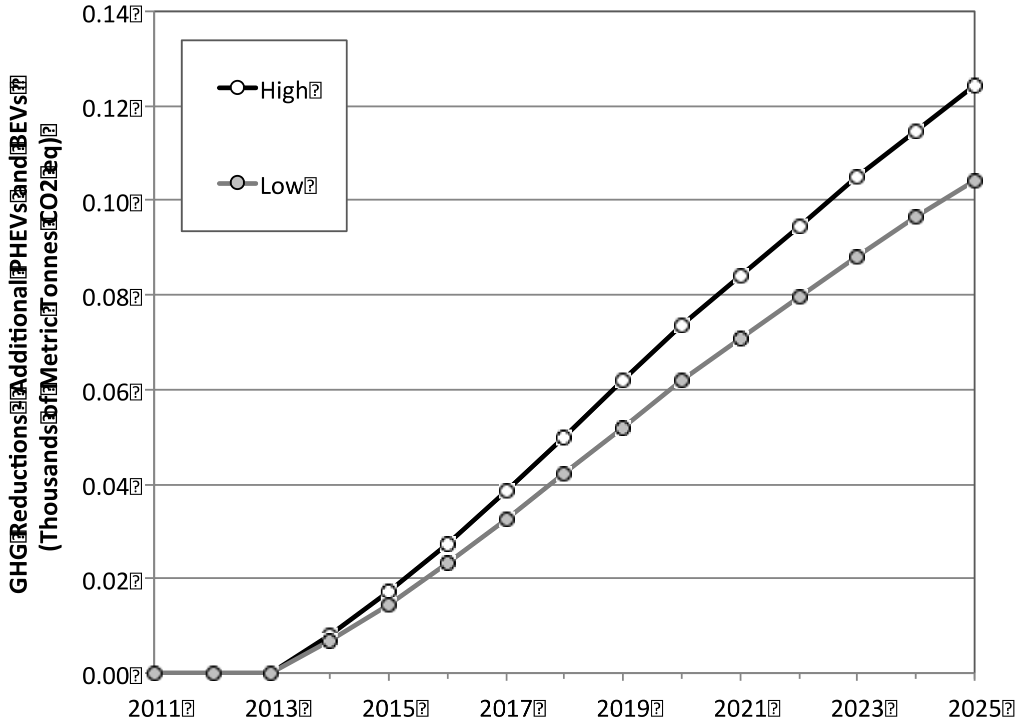


Figure 40: GHG and Petroleum Fuel Reductions from Investments in Manufacturing



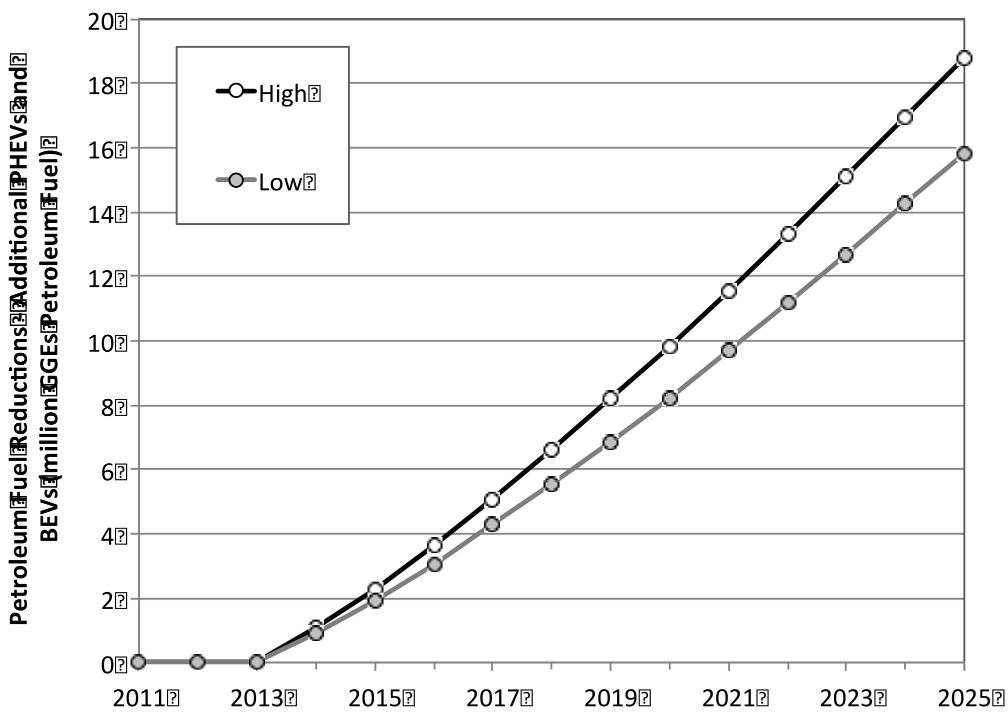


Table 27: Air Pollutant Emission Reductions due to Manufacturing and Component Demonstrations

Technology and Case		2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Additional VMT (billions)														
BEVs	High	-	0.02	0.05	0.08	0.12	0.16	0.20	0.25	0.29	0.35	0.40	0.46	0.51
	Low	-	0.02	0.04	0.07	0.10	0.13	0.17	0.21	0.25	0.29	0.33	0.38	0.43
PHEVs	High	-	0.02	0.05	0.08	0.12	0.16	0.20	0.25	0.29	0.35	0.40	0.46	0.51
	Low	-	0.02	0.04	0.07	0.10	0.13	0.17	0.21	0.25	0.29	0.33	0.38	0.43
TOTAL	High	-	0.04	0.10	0.16	0.23	0.31	0.40	0.49	0.59	0.69	0.80	0.91	1.03
	Low	-	0.04	0.08	0.13	0.19	0.26	0.33	0.41	0.49	0.58	0.67	0.76	0.86
ROG Emission Reductions (tonnes)														
BEVs	High	-	1.2	2.7	4.4	6.4	8.5	10.9	13.5	16.2	19.0	22.0	25.1	28.3
	Low	-	1.0	2.3	3.7	5.3	7.1	9.1	11.3	13.5	15.9	18.4	20.9	23.6
PHEVs	High	-	1.0	2.2	3.6	5.2	7.0	9.0	11.1	13.3	15.6	18.0	20.5	23.1
	Low	-	0.8	1.8	3.0	4.3	5.8	7.5	9.2	11.1	13.0	15.0	17.1	19.3
TOTAL	High	-	2.2	4.9	8.0	11.6	15.5	19.9	24.6	29.5	34.6	40.0	45.6	51.4
	Low	-	1.8	4.1	6.7	9.7	13.0	16.6	20.5	24.6	28.9	33.4	38.1	42.9
NOx Emission Reductions (tonnes)														
BEVs	High	-	1.5	3.4	5.6	8.1	10.9	13.9	17.2	20.6	24.2	28.0	31.9	36.0
	Low	-	1.3	2.9	4.7	6.8	9.1	11.6	14.4	17.2	20.2	23.4	26.7	30.0
PHEVs	High	-	1.1	2.5	4.0	5.8	7.8	10.0	12.3	14.7	17.3	20.0	22.8	25.7
	Low	-	0.9	2.0	3.3	4.8	6.5	8.3	10.3	12.3	14.4	16.7	19.0	21.5
TOTAL	High	-	2.6	5.9	9.6	13.9	18.6	23.9	29.5	35.4	41.5	48.0	54.7	61.7
	Low	-	2.2	4.9	8.0	11.6	15.6	19.9	24.6	29.5	34.7	40.1	45.7	51.5
PM2.5 (Total) Emission Reductions (tonnes)														
BEVs	High	-	0.2	0.4	0.7	1.0	1.4	1.8	2.2	2.7	3.1	3.6	4.1	4.6
	Low	-	0.2	0.4	0.6	0.9	1.2	1.5	1.8	2.2	2.6	3.0	3.4	3.9
PHEVs	High	-	-	-	-	-	-	-	-	-	-	-	-	-
	Low	-	-	-	-	-	-	-	-	-	-	-	-	-
TOTAL	High	-	0.2	0.4	0.7	1.0	1.4	1.8	2.2	2.7	3.1	3.6	4.1	4.6
	Low	-	0.2	0.4	0.6	0.9	1.2	1.5	1.8	2.2	2.6	3.0	3.4	3.9
CO Emission Reductions (1000 tonnes)														
BEVs	High	-	0.0	0.1	0.2	0.2	0.3	0.4	0.5	0.6	0.7	0.8	1.0	1.1
	Low	-	0.0	0.1	0.1	0.2	0.3	0.3	0.4	0.5	0.6	0.7	0.8	0.9
PHEVs	High	-	0.0	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.6
	Low	-	0.0	0.0	0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5
TOTAL	High	-	0.1	0.2	0.3	0.4	0.5	0.6	0.8	0.9	1.1	1.3	1.5	1.6
	Low	-	0.1	0.1	0.2	0.3	0.4	0.5	0.7	0.8	0.9	1.1	1.2	1.4

3.5 Next-Generation Fuel Production Facilities

The rationale for including fuel production projects in the Market Transformation category is that the specific production technologies funded may not have been executed without ARFVTP support, and that each project supported has the potential to be replicated at a larger "next generation" scale. The next generation facilities would be deployed at some point in time after the first project is completed and validated, and may or may not be deployed with further assistance from public funds. The estimated future capacity of next generation facilities is based upon survey capacity estimates received from awardees, with adjustments made for two factors: (1) scaling up the capacity of small production facilities to larger Next Generation plant capacities, and (2) scaling down Next Generation plant capacities if the ARFVTP funds provided are very small relative to the survey capacity estimate. These adjustments are applied such that the total capacity of all Next Generation plants is twice that of the total capacity of all Expected fuel production facilities. These two adjustment factors are discussed in detail below.

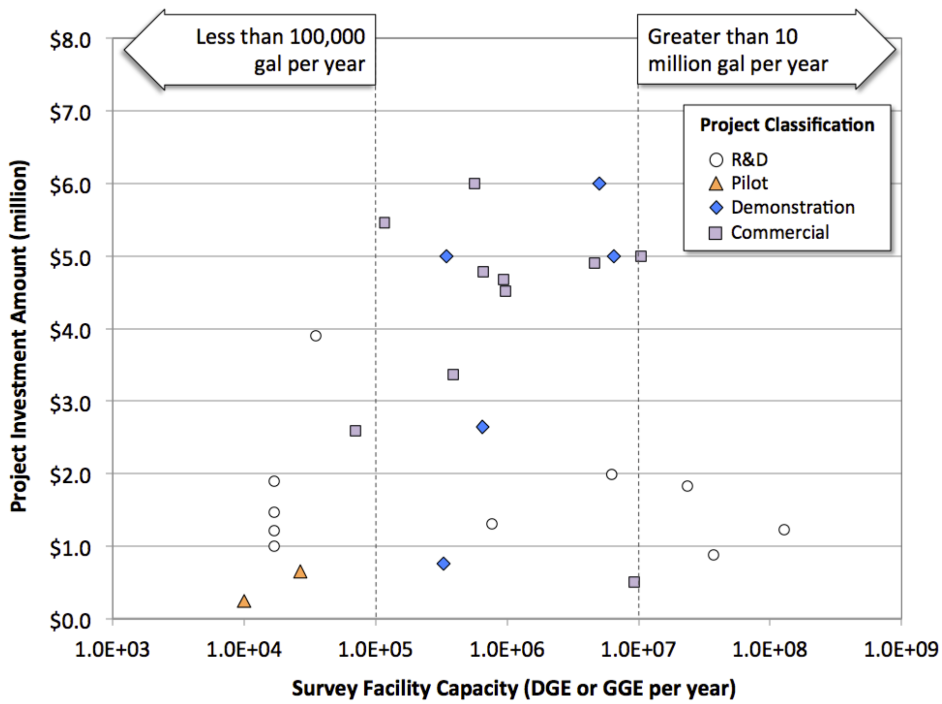
1. **Scaling Factor.** Market Transformation Benefits are accrued for the volume of fuel provided by one additional next generation facility. Fuel production projects with relatively small survey capacity estimates (less than 1 million gallons per year) are scaled by the scaling factor to estimate larger Next Generation plants. Projects with relatively large survey capacity estimates (greater than 1 million gallons per year) are assumed to be deployed a second time at the same scale. In the High Benefits case, 100% of the volume from next generation plants is allocated and the plants are installed 3 years after completion of the initial facility supported by ARFVTP. In the Low Benefits case, 25% of the volume is allocated and plants are installed 5 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.** It is assumed that Market Transformation benefits decline as the ratio of survey production capacity (gallons per year) to funding support provided (dollars from ARFVTP) begins to exceed 1 gallon per year per dollar. The percent of facility capacity allocated declines exponentially as this ratio increases, reaching 5% for a facility having a ratio of approximately 100 gallons per year per dollar. Given this parameter definition, the adjustment results in a significant reduction (e.g. greater than 1%) 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.

The result of applying these two adjustments is that of the approximately 41 million gallons per year in production volume accrued as Expected Benefits, including pilot, demonstration, and commercial plants but excluding R&D plants, Market Transformation benefits are based upon a total capacity of approximately 82 million gallons per year of Next Generation fuel production capacity.

The rationale for adjusting the original production volumes provided through the Energy Commission survey of awardees can be understood by examining Figure 41. The figure indicates the total ARFVTP investment per project in millions of dollars on the vertical axis and the production capacity provided through the survey, in gallons per year, on the horizontal axis (using a logarithmic scale). The project type (R&D, pilot, demonstraton, and commercial) is indicated by symbol shape and color. Facility capacities range across four orders of magnitude, and can be separated into three groups: small facilities having capacities less than 100,000 gallons per year, large facilities with capacities greater than 10 million gallons per year, and facilities falling in a medium category in the range of 100,000 to 10 million gallons per year.

In general, most pilot and R&D projects are in the small capacity range, while most commercial facilities are within the medium capacity range. However, the amount of funding provided on a project basis does not increase consistently with larger capacities, which is especially significant for several R&D projects within the medium and large capacity groups (note that the horizontal axis is log scale, while the vertical axis is linear). These projects are funded at roughly the same level ($1-$2 million) as smaller-capacity R&D projects, but would be allocated much larger benefits if no adjustments were made. Moreover, these R&D projects are funded at lower levels than many commercial and demonstration projects with more prove technologies but lower survey capacity estimates. Given that these capacities are estimates, and that the R&D technologies would tend to be less proven than projects in the other categories, it is reasonable to adjust the associated benefits so as not to overshadow the benefits associated with other projects.

Figure 41: Investment amount and survey fuel production capacity by project type



This is not to say that the survey responses are incorrect relative to one another, but rather that ARFVTP funds can only be leveraged to a limited degree for any given technology. If an R&D project does eventually end up being deployed at the 10-100 million gallon per year scale, this does not necessarily imply that the benefits of that future facility should be accrued to ARFVTP in the same proportion as other R&D projects funded by ARFVTP at the $1-3 million dollar per project level. Bringing an R&D phase technology to full commercialization may require additional program support, or be subject to significant learning and innovation that builds upon the progress originally achieved through ARFVTP support.

The first scaling factor adjustment increases the Next Generation plant capacities by a greater degree for smaller plants than for larger plants. This factor is a function of the survey capacity, and is calibrated such that, when combined with the second volume-to-funding ratio, total Market Transformation capacities in aggregate are twice the total capacity of the facilities with expected benefits.

The second scaling factor is a function of the volume-to-funding ratio (R_{VF}), defined as the survey capacity in gallons per year divided by the total ARFVTP funding amount. The adjustment is made such that benefits accrued to ARFVTP begin to drop significantly when the ratio begins to exceed 1.0 gallon per year per dollar, and declines to 5% of the survey capacity when the ratio reaches 100 gallons per year per dollar. Specifically, the adjustment factor has been calibrated to meet these two outcomes: (1) a 0.5% reduction for a ratio of 1.0, and (2) a 95% reduction for a ratio of 100. Lacking an appropriate theoretical or empirical model, this adjustment is made assuming the percent of expected capacity allocated as benefits drops off exponentially as a function of the Volume-to-Funding (R_{VF}) ratio:

$$V_{MT} = V_{Expt}\left(1 - exp\left[\frac{\beta}{R_{VF}}\right]\right)$$

Where,

V_{MT} =	Production volume allocated to Market Transformation benefits (GGE/DGE per yr)
V_{Expt} =	Production volume allocated to Expected benefits (GGE/DGE per yr)
R_{VF} =	Volume-to-Funding Ratio (gallons per year per dollar of ARFVTP funding)
β =	Calibration factor to meet 5% reduction by R_{VF} = 100 (equal to -5.204)

The resulting adjustment factor is indicated in Figure 42. This adjustment results in a significant change in the capacity used to estimate MT benefits for seven projects (see below). Note that the assumption that the future benefits associated with 1 gallon per year of fuel production capacity are allocated to an investment of $1 is an optimistic assumption, and that allocating 5% of 100 gallons per day for an investment of $1 is even more optimistic, with the later being equivalent to 5 gallons per year per $1 invested. Therefore, even though the percent of expected production volume allocated declines rapidly, the capacity per dollar is continuously increasing.

The effects of applying both the Scaling Factor and Volume-to-Funding Ratio adjustments are compared to survey fuel production capacities in Figure 43. Four types of fuel production capacities are indicated as increasing cumulatively across projects, beginning with projects that have low Volume-to-Funding Ratios on the left and finishing with the project with the highest Volume-to-Funding Ratio on the right (ARV-10-023). Cumulative Expected production capacity increases gradually to about 41 million gallons per day near a Volume-to-Funding Ratio of abut 18, then levels off as the two subsequent projects are only analyzed within the MT Benefits category. In contrast, the total survey capacity is shown increasing significantly at higher VtF ratios, primarily due to those additional two projects, and the cumulative capacity with the scaling factor applied is even larger. Applying the second adjustment factor reduces the capacity contribution from projects with large VtF ratios, resulting in a cumulative Market Transformation capacity of 82 million gallons per year. Shifts in capacity for each project are indicated in Figures 44 and 45, and Tables 28, 29, and 30 review the fuel production inputs and results on a project level. Table 31 indicates the resulting GHG reductions and fuel use reductions, and Figures 46 and 47 show the same results super-imposed on each other to indicate relative magnitudes.

Figure 42: Volume-to-Funding Ratio Adjustment

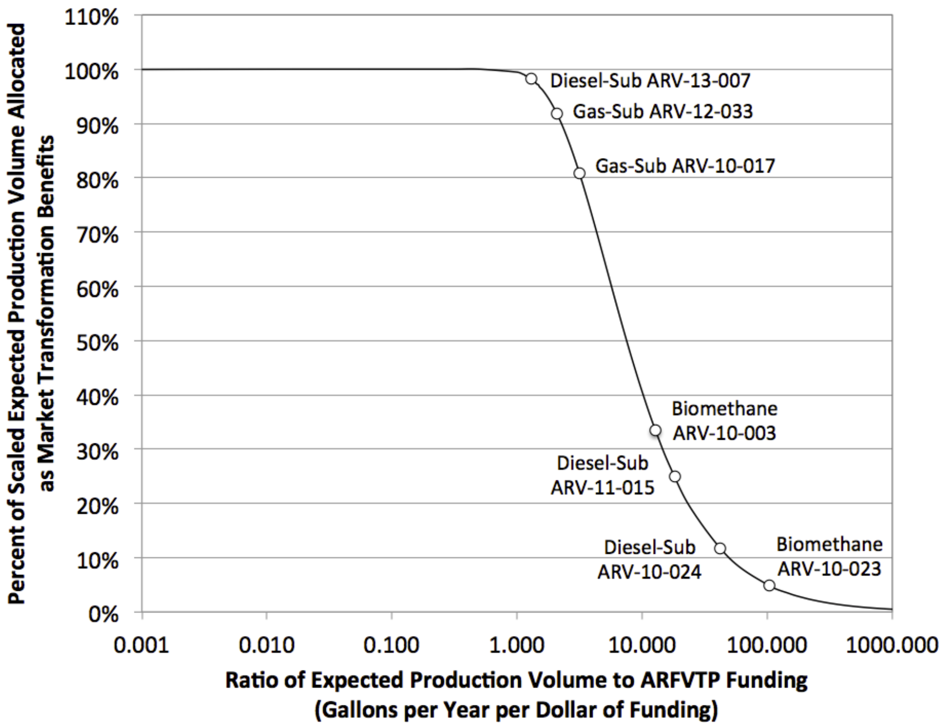


Figure 43: Cumulative Capacities as a Function of the Volume-to-Funding Ratio

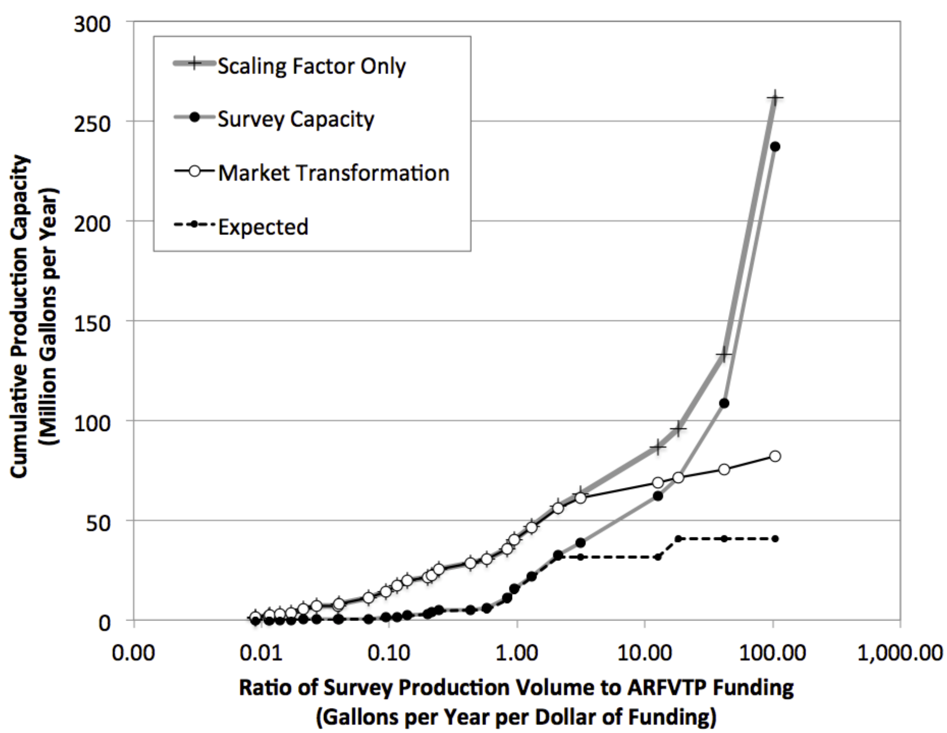


Figure 44: Facility Capacity Changes Resulting from the Scaling Factor Adjustment

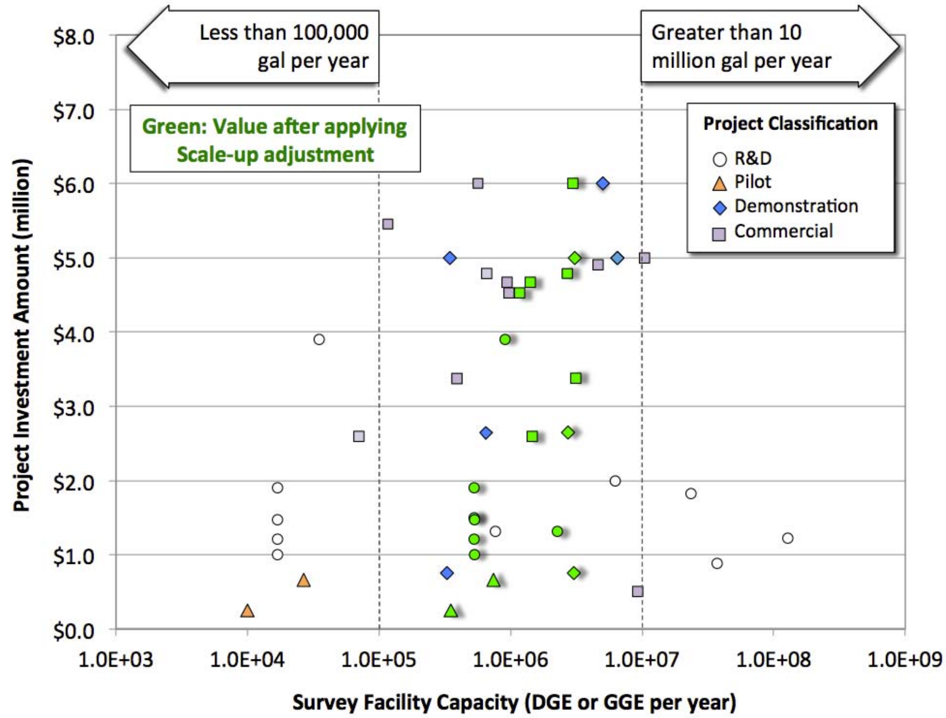


Figure 45. Facility Capacity Changes Resulting from the Volume-to-Funding Adjustment

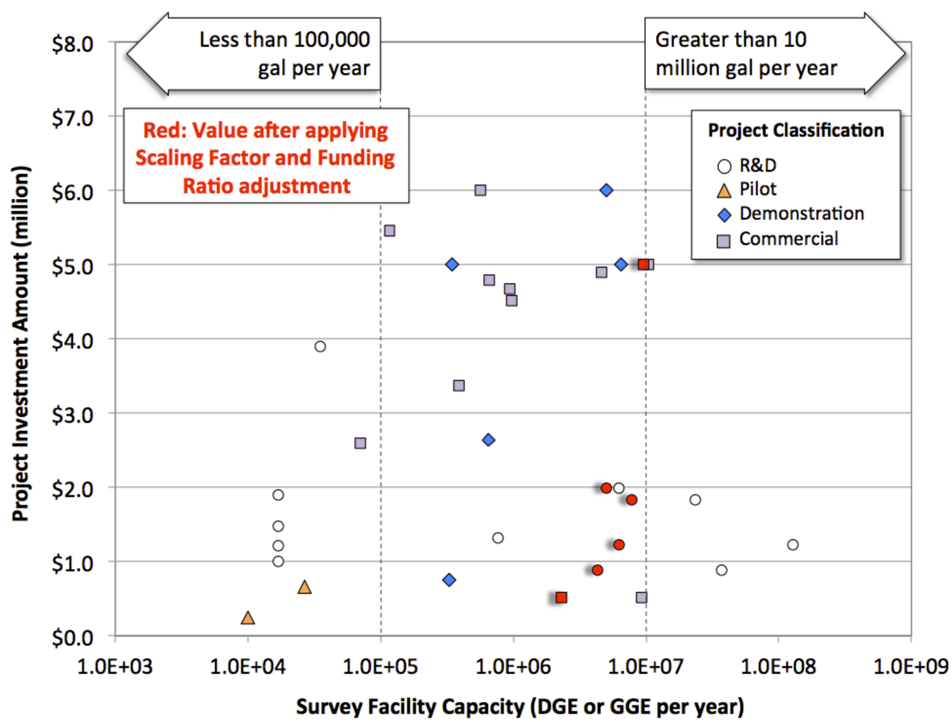


Table 28: Summary of Fuel Production Projects and Annual Outputs

Project #	Awardee	Fuel Product	Funding ($M)	Project End Date	Survey Reported Capacity Output	Survey Reported Capacity Units	Normalized Output (DGE or *GGE* per yr)
ARV-11-015	New Leaf Biofuels	Biodiesel	$0.51	3/15/14	10,000,000	gal BD/yr	9,307,123
ARV-12-026	Eslinger Biodiesel, Inc.	Biodiesel	$6.00	3/31/15	5,000,000	DGE/yr	5,000,000
ARV-13-007	Crimson Renewable Energy LP	Biodiesel	$5.00	12/31/16	7,000,000	BD gal/yr	6,514,986
ARV-13-008	American Biodiesel, Inc.	Biodiesel	$4.90	12/31/16	5,000,000	BD gal/yr	4,653,562
ARV-11-016	Springboard Biodiesel	Biodiesel	$0.76	3/31/14	41,825	MMBTU/yr	325,613
ARV-10-024	Biodico	Biodiesel	$0.89	3/16/14	40,000,000	BD gal/yr	37,228,494
ARV-10-022	East Bay Municipal Utility District	Biodiesel	$1.00	12/30/13	100	BD gal/yr	16,959
ARV-10-016	City of San Jose	Gas	$1.90	4/30/15	none	na	16,959
ARV-10-026	Clean World Partners, LLC	Gas	$1.32	3/30/15	98,550	MMBtu/yr	767,225
ARV-12-021	Environ Strategy Consultants, Inc.	Gas	$1.21	6/30/14	none	na	16,959
ARV-10-023	G4 Insights, Inc.	Gas	$1.23	3/31/14	16,500,000	MMBTU/yr	128,454,652
ARV-12-064	Harvest Power California LLC	Gas	$4.79	12/30/16	660,000	DGE/yr	660,000
ARV-12-031	Blue Line Transfer, Inc.	Gas	$2.59	8/31/15	8,991	MMBtu/yr	69,996
ARV-10-052	CR&R Incorporated	Gas	$4.52	3/31/15	125,000	MMBtu/yr	973,141
ARV-10-053	Pixley Biogas LLC	Gas	$4.67	3/1/16	120,000	MMBtu/yr	934,216
ARV-10-040	Northstate Rendering Co Inc.	Gas	$5.46	4/15/14	15,000	MMBtu/yr	116,777
ARV-10-003	Sacramento Municipal Utility District	Gas	$1.83	6/1/15	3,000,000	MMBtu/yr	23,355,391
ARV-11-021	Clean World Partners	Gas	$6.00	6/30/14	566,027	DGE/yr	566,027
ARV-10-049	Biostar Systems, LLC	NG	$3.37	8/30/15	54,000,000	SCF/yr	390,969
ARV-12-033	Mendota Bioenergy, LLC (MBLLC)	Ethanol	$5.00	8/30/15	15,000,000	EtOH gal/yr	***10,430,257***
ARV-11-018	EdeniQ	Ethanol	$3.90	12/30/14	50,000	EtOH gal/yr	***34,768***
ARV-10-017	Great Valley Energy, LLC	Ethanol	$1.99	6/28/13	9,000,000	EtOH gal/yr	***6,258,154***
ARV-10-028	Mendota Advanced Bioenergy Beent	Ethanol	$1.50	3/1/15	none	na	***16,959***
ARV-11-019	SacPort Biofuels Corporation	FT Diesel	$5.00	3/1/15	360,000	FTD gal/yr	344,165
ARV-12-035	Buster Biofuels LLC	Biodiesel	$2.64	1/16/16	700,000	BD gal/yr	651,499
ARV-10-047	Solazyme, Inc.	RD	$1.47	3/18/15	45	DGE/yr	16,959
ARV-10-027	Cal Poly State Univ., San Luis Obispo	RD	$0.25	4/30/13	10,000	DGE/yr	10,000
ARV-10-043	Agricultural Waste Solutions, Inc.	RD	$0.66	8/8/14	29,200	RD gal/yr	26,611
SUM			**$80.36**				**237,158,420**

Table 29: Fuel Production Project Adjustments and Market Transformation Output

Awardee	Fuel Product	Normalized Output (DGE or *GGE*]	Expected (1=yes)	Expected Output (DGE or GGE)	Scaling Adj.	VtF Adj.	Combined Adj.	Market Transformation Output (DGE/GGE)
New Leaf Biofuels	Biodiesel	9,307,123	1	9,307,123	1.00	24.9%	0.25	2,316,869
Eslinger Biodiesel, Inc.	Biodiesel	5,000,000	1	5,000,000	1.00	99.8%	1.00	4,990,302
Crimson Renewable Energy LP	Biodiesel	6,514,986	1	6,514,986	1.00	98.2%	0.98	6,394,959
American Biodiesel, Inc.	Biodiesel	4,653,562	1	4,653,562	1.00	99.6%	1.00	4,634,253
Springboard Biodiesel	Biodiesel	325,613	1	325,613	9.35	100.0%	9.35	3,042,857
Biodico	Biodiesel	37,228,494	0	0	1.00	11.7%	0.12	4,340,681
East Bay Municipal Utility District	Biodiesel	16,959	0	0	31.32	100.0%	31.32	531,192
City of San Jose	Gas	16,959	0	0	31.32	100.0%	31.32	531,192
Clean World Partners, LLC	Gas	767,225	0	0	2.97	100.0%	2.97	2,278,907
Environ Strategy Consultants, Inc.	Gas	16,959	0	0	31.32	100.0%	31.32	531,192
G4 Insights, Inc.	Gas	128,454,652	0	0	1.00	4.9%	0.05	6,244,304
Harvest Power California LLC	Gas	660,000	1	660,000	4.09	100.0%	4.09	2,699,624
Blue Line Transfer, Inc.	Gas	69,996	1	69,996	20.78	100.0%	20.78	1,454,400
CR&R Incorporated	Gas	973,141	1	973,141	1.20	100.0%	1.20	1,170,192
Pixley Biogas LLC	Gas	934,216	1	934,216	1.51	100.0%	1.51	1,407,020
Northstate Rendering Co Inc.	Gas	116,777	1	116,777	16.97	100.0%	16.97	1,981,899
Sacramento Municipal Utility District	Gas	23,355,391	0	0	1.00	33.5%	0.33	7,821,662
Clean World Partners	Gas	566,027	1	566,027	5.23	100.0%	5.23	2,961,851
Biostar Systems, LLC	NG	390,969	1	390,969	7.98	100.0%	7.98	3,121,742
Mendota Bioenergy, LLC (MBLLC)	Ethanol	***10,430,257***	***1***	***10,430,257***	***1.00***	***91.7%***	***0.92***	***9,568,968***
EdeniQ	Ethanol	***34,768***	***0***	***0***	***25.98***	***100.0%***	***25.98***	***903,352***
Great Valley Energy, LLC	Ethanol	***6,258,154***	***0***	***0***	***1.00***	***80.9%***	***0.81***	***5,061,175***
Mendota Advanced Bioenergy Beent	Ethanol	***16,959***	***0***	***0***	***31.32***	***100.0%***	***31.32***	***531,192***
SacPort Biofuels Corporation	FT Diesel	344,165	1	344,165	8.93	100.0%	8.93	3,074,407
Buster Biofuels LLC	Biodiesel	651,499	1	651,499	4.19	100.0%	4.19	2,727,669
Solazyme, Inc.	RD	16,959	0	0	31.32	100.0%	31.32	531,192
Cal Poly State Univ., San Luis Obispo	RD	10,000	1	10,000	35.25	100.0%	35.25	352,503
Agricultural Waste Solutions, Inc.	RD	26,611	1	26,611	27.97	100.0%	27.97	744,329
SUM		**237,158,420**		**40,974,942**				**81,949,884**

Table 30: Fuel Production Project Expected and Market Transformation GHG Reductions

Awardee	Fuel Product	Source	FCI (gCO2e/ MJ)	GHG Emissions (1000 tonnes CO2e/year) Expected Reduced	Market Trans. High	Market Trans. Low
New Leaf Biofuels	Biodiesel	used cooking oil (UCO, w "cooking"	15.8	103.67	25.81	6.45
Eslinger Biodiesel, Inc.	Biodiesel	80% tallow, 20% UCO	11.5	58.64	58.53	14.63
Crimson Renewable Energy LP	Biodiesel	Project-defined	12.0	75.96	74.56	18.64
American Biodiesel, Inc.	Biodiesel	Project-defined	59.0	24.61	24.51	6.13
Springboard Biodiesel	Biodiesel	used cooking oil (UCO, w "cooking"	15.8	3.63	33.89	8.47
Biodico	Biodiesel	80% UCO, 10% algae, 10% rapeseed	22.0	0.00	44.74	11.18
East Bay Municipal Utility District	Biodiesel	used cooking oil (UCO, w "cooking"	15.8	0.00	5.92	1.48
City of San Jose	Gas	50% dairy waste, 50% wood waste	18.4	0.00	5.73	1.43
Clean World Partners, LLC	Gas	50% dairy waste, 50% wood waste	18.4	0.00	24.60	6.15
Environ Strategy Consultants, Inc.	Gas	dairy digester Biogas to CNG	13.5	0.00	6.09	1.52
G4 Insights, Inc.	Gas	50% dairy waste, 50% wood waste	18.4	0.00	67.42	16.85
Harvest Power California LLC	Gas	landfill gas, pipeline quality,	11.3	7.76	31.75	7.94
Blue Line Transfer, Inc.	Gas	dairy digester Biogas to CNG	13.5	0.80	16.67	4.17
CR&R Incorporated	Gas	dairy digester Biogas to CNG	13.5	11.15	13.41	3.35
Pixley Biogas LLC	Gas	dairy digester Biogas to CNG	13.5	10.71	16.13	4.03
Northstate Rendering Co Inc.	Gas	dairy digester Biogas to CNG	13.5	1.34	22.72	5.68
Sacramento Municipal Utility District	Gas	waste water treatment AD w/CCS	(178.5)	0.00	293.08	73.27
Clean World Partners	Gas	dairy digester Biogas to CNG	13.5	6.49	33.95	8.49
Biostar Systems, LLC	NG	dairy digester Biogas to CNG	13.5	4.48	35.78	8.95
Mendota Bioenergy, LLC (MBLLC)	Ethanol	80% sugarbeets, 20% forest residues	30.9	***82.43***	***75.62***	***18.90***
EdeniQ	Ethanol	90% corn stover, 10% wood waste	35.2	***0.00***	***6.69***	***1.67***
Great Valley Energy, LLC	Ethanol	Brazilian sugarcane with ave. credits	20.4	***0.00***	***46.18***	***11.54***
Mendota Advanced Bioenergy Beent	Ethanol	80% sugarbeets, 20% forest residues	30.9	***0.00***	***4.20***	***1.05***
SacPort Biofuels Corporation	FT Diesel	MSW FT Diesel	25.7	3.37	30.13	7.53
Buster Biofuels LLC	Biodiesel	used cooking oil (UCO, w "cooking"	15.8	7.26	30.38	7.60
Solazyme, Inc.	RD	algae oil transesterification	53.9	0.00	3.18	0.79
Cal Poly State Univ., San Luis Obispo	RD	algae oil transesterification	53.9	0.06	2.11	0.53
Agricultural Waste Solutions, Inc.	RD	dairy waste pyrolysis	20.2	0.28	7.85	1.96
SUM				**402.64**	**1041.63**	**260.41**

Table 31. GHG and petroleum reductions from next generation biofuel estimates

GHG Reductions (MMTCO2e)

Fuel Category and Case	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
Full Expansion													
Biomethane	-	-	-	-	0.00	0.04	0.17	0.37	0.52	0.56	0.57	0.57	0.57
Diesel Substitute	-	-	-	-	0.00	0.04	0.11	0.20	0.28	0.32	0.34	0.34	0.34
Gasoline Substitute	-	-	-	-	0.01	0.03	0.06	0.09	0.12	0.13	0.13	0.13	0.13
TOTAL	-	-	-	-	0.01	0.11	0.34	0.66	0.92	1.01	1.04	1.04	1.04
25% with 2-year delay													
Biomethane	-	-	-	-	-	-	0.00	0.01	0.04	0.09	0.13	0.14	0.14
Diesel Substitute	-	-	-	-	-	-	0.00	0.01	0.03	0.05	0.07	0.08	0.09
Gasoline Substitute	-	-	-	-	-	-	0.00	0.01	0.01	0.02	0.03	0.03	0.03
TOTAL	-	-	-	-	-	-	0.00	0.03	0.09	0.16	0.23	0.25	0.26

Petroleum Fuel Reductions (million DGE/GGE)

Fuel Category and Case	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**
Full Expansion													
Biomethane	-	-	-	-	0.00	3.36	11.19	21.84	29.14	31.53	32.20	32.20	32.20
Diesel Substitute	-	-	-	-	0.12	3.90	10.75	18.41	26.53	30.92	33.68	33.68	33.68
Gasoline Substitute	-	-	-	-	0.97	2.99	6.34	11.18	14.76	16.06	16.06	16.06	16.06
TOTAL	-	-	-	-	1.09	10.25	28.27	51.43	70.42	78.52	81.95	81.95	81.95
25% with 2-year delay													
Biomethane	-	-	-	-	-	-	0.00	0.84	2.80	5.46	7.28	7.88	8.05
Diesel Substitute	-	-	-	-	-	-	0.03	0.97	2.69	4.60	6.63	7.73	8.42
Gasoline Substitute	-	-	-	-	-	-	0.24	0.75	1.59	2.80	3.69	4.02	4.02
TOTAL	-	-	-	-	-	-	0.27	2.56	7.07	12.86	17.60	19.63	20.49

Figure 46. Market Transformation Fuel Production GHG Reductions by fuel type

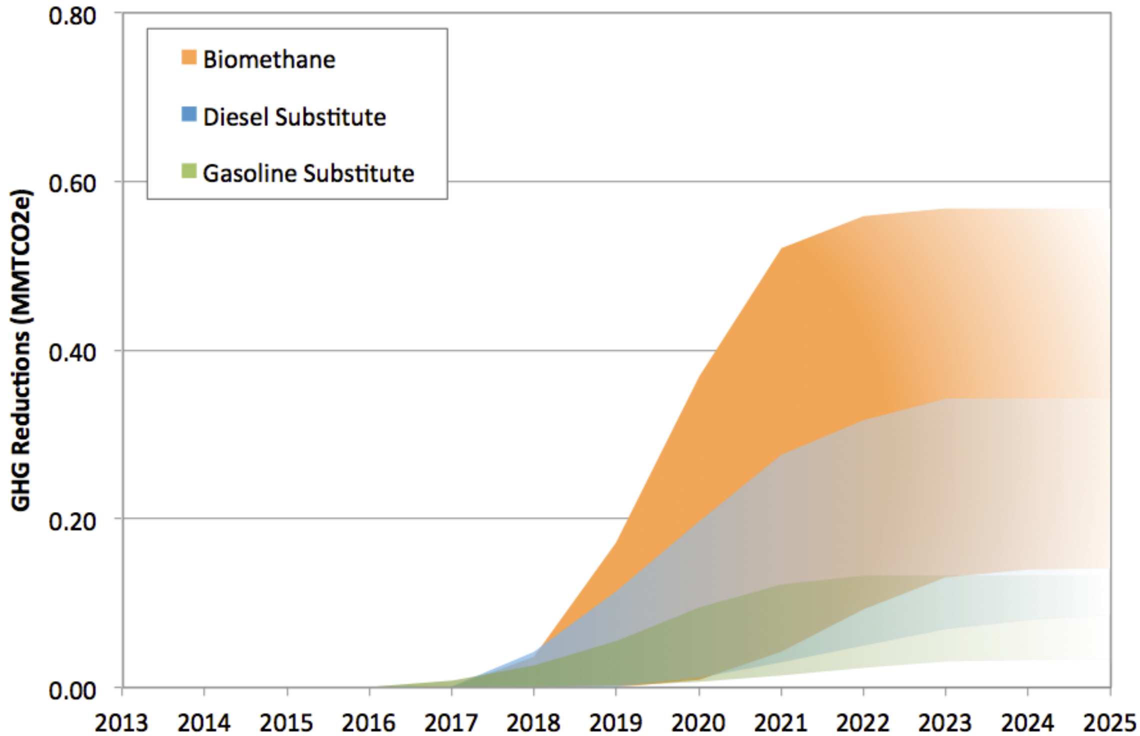
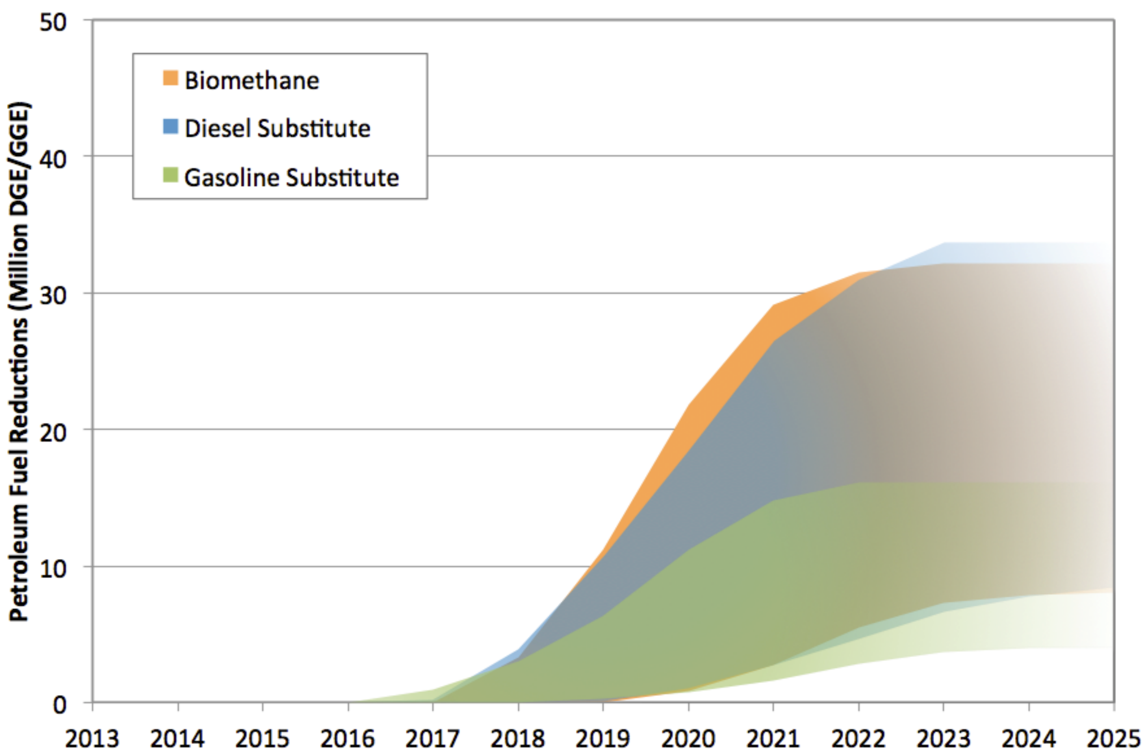


Figure 47. Market Transformation Fuel Production Petrol Fuel Reductions by fuel type



3.6 Next-Generation Advanced Truck Demonstrations

Data available from project survey results on future market impacts of advanced truck projects are similar to data on advanced fuel production projects. For this reason, a similar approach to the scale-up of fuel production facilities is also applied to advanced truck projects to estimate market transformation benefits. In general, the number of trucks deployed in future years is projected for high and low cases, based upon survey data and funding levels for three categories: electric drive, natural gas, and gasoline substitutes.

Given the sparse data on future market impacts of advanced trucks, benefit estimate assumptions are extrapolated across multiple projects to provide proxy values were data are missing. In addition, a project-level cost of carbon metric ($ per tonne CO_2e) is used to compare high and low cases across the three categories. This metric is relied upon to provide a bound on input assumptions lacking empirical data but is not intended to be an estimate of project abatement costs. It is anticipated that as additional data are collected at the project level, more reliable estimates of carbon abatement costs can be developed using the same methodological framework.

A description of the key market adoption assumptions used to estimate low and high case next-generation advanced truck benefits are summarized in Table 32. The general approach is to rely upon reasonable high and low case input assumptions derived from different types of project survey data, such as the ratio of fuel reductions per dollar of project funding (DGE/$) or the number of future vehicles deployed per dollar of project funding (number of vehicles per dollar). These values are generally taken from one particular project within the category and then extrapolated across the other projects in the same category. The result is either the quantity of fuel displaced or the number of additional vehicles deployed due to influence on future market adoption dynamics. Both results can be resolved in terms of future nominal medium- and heavy-duty diesel vehicles displaced.

These assumptions are based upon unique data provided through ARFVTP projects and are not necessarily representative of electric drive, natural gas, or gasoline substitute trucks in general. For example, the gasoline substitute trucks are hybridized, and the high and low case estimates for natural gas vehicles are based upon assumptions for medium- and heavy-duty trucks, respectively. As additional data are received at the project level, fewer extrapolations across projects lacking data will be required, and specific use and duty cycle assumptions (for example, VMT per year and fuel economy) will be developed for each project. Until consistent data become available across multiple projects, more general representations will be required to estimate benefits associated with AFVTP funds invested in each category.

Fuel economy, VMT per year, and resulting fuel use per year values for the nominal vehicles are indicated for medium (Class 4-6) and heavy (Class 7-8) trucks in Table 33. It is assumed that natural gas MDTs have 10 percent greater fuel economy than the nominal MDTs, electric MDTs have 20 percent greater fuel economy than the nominal MDTs, and electric HDTs have 5 percent greater fuel economy than the nominal HDTs. Moreover, ethanol used in the gasoline substitute trucks has 97 percent of the carbon intensity of conventional diesel, and natural gas is assumed to have 71 percent of the carbon intensity of conventional diesel.

The project-level reference values described in Table 33 result in the effectiveness values for each advanced truck category and case in Table 34. These metrics indicate the resulting fuel displaced, GHGs displaced, and additional trucks deployed per ARFVTP funding provided to all projects in each category. The final column indicates the nominal dollars per tonne CO_2e reduced by category. Additional HDTs are deployed only in the electric truck category. In general, metrics are tenfold greater in the high case than in the low case, with the carbon metric being inverted in this respect. The ratio of the low metric to the high metric is indicated for each category as a percentage. The ratio is about 10 percent for electric and gasoline substitute and 16 percent for gaseous trucks. The following trends are also notable in considering the relatively effectiveness of funds among category types:

- There are a far greater number of gasoline substitute trucks deployed per dollar of funding than electric or natural gas.
- GHG reductions per dollar are comparable in the electric and natural gas categories, but both are far less than in the gasoline substitute category.
- Fuel displaced per dollar of funding is greater in the gaseous and gasoline substitute categories than in the electric truck category.

Table 32: Key Low and High Case Assumptions for Next-Generation Advanced Truck Benefits

Category	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 HVIP. • 162,200 DGE reduced and $4.0M invested is 41 DGE per $1000	The number of additional vehicles deployed per dollar of project funding is assumed to be equal to the first year of market potential suggested in project survey data provided for the largest single project (CALSTART's CLEAN Truck Demonstration Program, ARV-11-014). • 3000 MDTs and 4500 HDTs deployed and $18M invested is 738 MDTs and 323 HDTs 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 MDTs, scaled to 250 MDTs, and $4.56M invested is 55 MDTs 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 HDTs and $1.46M invested is 343 HDTs 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 MDTs and $2.7M invested is 369 MDTs 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 MDTs and $2.7M invested is 3,687 MDTs per $1.0M invested

Table 33: Base Assumptions for Nominal Diesel Vehicles Displaced by Future Market Adoption of Advanced Truck Technologies

Vehicle Class	Fuel Economy (mi/DGE)	Utilization (miles per year)	Fuel Use per Vehicle (DGE/yr/veh)
4-6	7.3	19,800	2,715
7-8	4.0	98,000	24,810

The absolute value results for each advanced truck category corresponding to the effectiveness metrics are summarized in Table 35. The additional vehicles adopted apply to aggregate funding provided to all projects within each category, and the fuel use, petroleum fuel use reductions, and GHG reductions follow from the estimated additional vehicles deployed. GHG reductions follow from assumptions noted above on relative carbon intensity of natural gas and corn ethanol. Though some of the trucks in the electric category will likely be plug-in vehicles, sufficient data are not available to account explicitly for the substitution of electricity for diesel. The general assumptions of a 20 percent increase in MDV fuel economy and a 5 percent increase in HDV fuel economy can also be improved with additional project-level data. Some of these data are being generated through on-road testing of demonstration vehicles.[63] The petroleum fuel and GHG reductions indicated represent full deployment of the additional vehicles, while the actual benefits accrued by year with an assumed linearly increasing ramp-up rate between 2014 and 2018. The resulting GHG and petroleum fuel reductions for each the high and low cases for each category are indicated in Figure 48.

Table 34: Relative Effectiveness Metrics for Advanced Truck Projects

Category and Case	Fuel Displaced	GHGs Displaced	Additional Trucks/Funding		Carbon Metric
	DGE/$1000/yr	kg CO2e/$/yr	MDT/$M	HDT/$M	$/Tonne CO2e
M-HD Electric Trucks					
High	401	5.3	738	323	15.64
Low	41	0.5	75	33	154.56
low/high (percent)	*10%*	*10%*	*10%*	*10%*	-
MD Gaseous Trucks					
High	931	4.3	343	-	19.21
Low	149	0.7	55	-	120.16
low/high (percent)	*16%*	*16%*	*16%*	-	-
MD Gasoline Sub Trucks					
High	10,010	4.0	3,687	-	20.66
Low	1,001	0.4	369	-	206.63
low/high (percent)	*10%*	*10%*	*10%*	-	-

63 Reference to forthcoming NREL report on data logging results. Thornton et al. (Forthcoming).

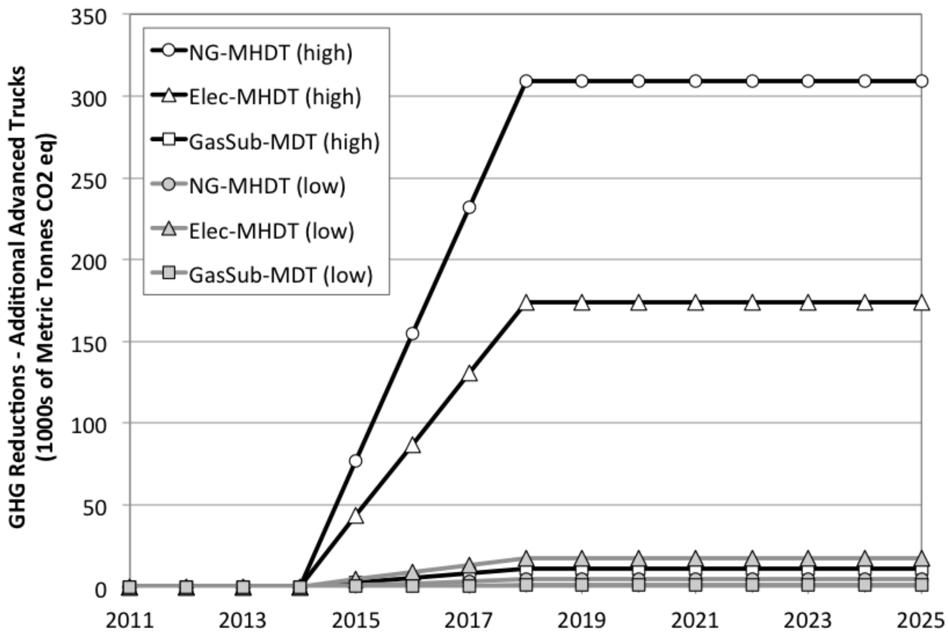
Table 35: Benefit Results by Advanced Truck Category and Case

Advanced Truck Category and Case	Number of Vehicles (additional)	New Fuel Economy (MPDGE)	Fuel Use per Vehicle (DGE/yr/veh)	Fuel Use Total (M DGE/yr)	PetrolFuel Reduced (M DGE/yr)	GHG Reduction (MMTCO2e/yr)
Electric MDTs						
High	5,455	9.1	2,172	11.85	2.96	0.039
Low	552	9.1	2,172	1.20	0.30	0.004
Electric HDTs						
High	8,182	4.2	23,570	106.06	10.15	0.135
Low	828	4.2	23,570	106.06	1.03	0.014
Gaseous M/HDTs						
High (HDTs)	2,673	4.3	22,555	60.29	66.32	0.3092
Low (MDTs)	427	7.3	2,715	1.16	1.16	0.0044
Gasoline Sub MDTs						
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

3.7 Summary of Market Transformation Benefits

Sections 3.2 through 3.6 above have reviewed the approach, assumptions, and benefit results associated with each market transformation influence. The high and low case results discussed in the previous sections, for vehicle price reductions, vehicle production cost reductions, and next-generation fuel production and advanced truck demonstrations, are summarized in Table 36. The next chapter reviews the fourth and final benefits type, Carbon Market Growth Requirements.

Figure 48: GHG and Petroleum Fuel Reduction Cases for Advanced Truck Categories



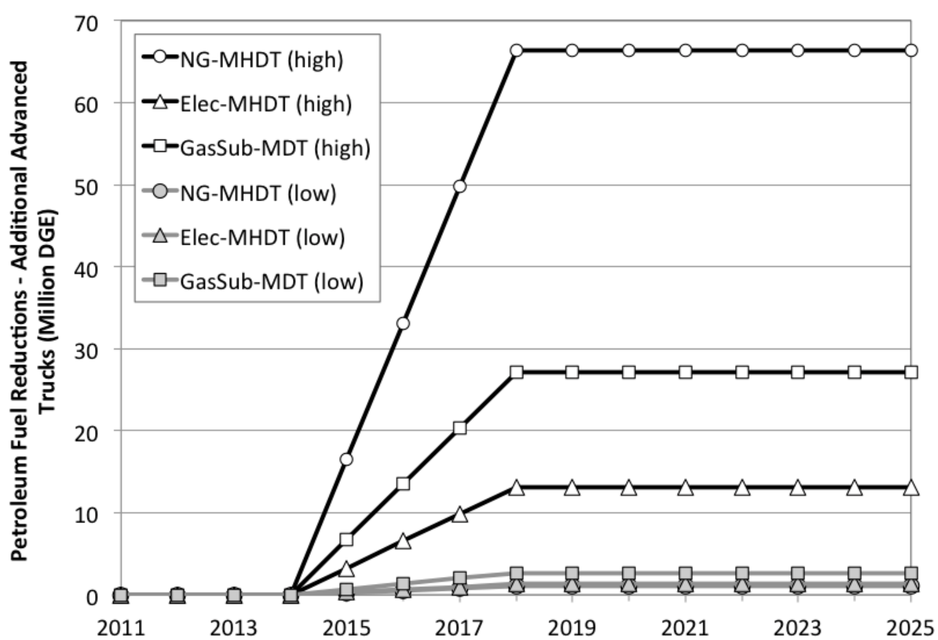


Table 36: Summary of Market Transformation GHG and Petroleum Fuel Reductions

GHG Reductions (10^3 Tonnes CO2e)	Case	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Vehicle Price Reductions	High	181.2	279.1	309.8	348.7	394.0	443.9	499.8	563.8	614.9	651.8	675.8	698.6	720.4
	Low	185.6	280.3	304.4	332.3	361.9	391.9	424.0	457.5	484.3	509.2	532.0	553.7	574.2
ZEV Industry Experience	High	-	16.0	34.2	54.4	76.2	99.0	122.4	145.7	166.6	187.3	207.5	227.0	245.5
	Low	-	13.4	28.6	45.5	63.8	82.9	102.5	122.0	139.5	156.8	173.8	190.1	205.6
Next-Generation Trucks	High	-	-	123.6	247.2	370.8	494.5	494.5	494.5	494.5	494.5	494.5	494.5	494.5
	Low	-	-	5.79	11.57	17.36	23.14	23.14	23.14	23.14	23.14	23.14	23.14	23.14
Next-Generation Fuels	High	-	-	-	-	9.7	105.3	341.6	659.7	918.8	1,009.0	1,041.6	1,041.6	1,041.6
	Low	-	-	-	-	-	-	2.4	26.3	85.4	164.9	229.7	252.2	260.4
Total	High	181.2	295.1	467.6	650.3	850.7	1,142.6	1,458.3	1,863.6	2,194.7	2,342.5	2,419.5	2,461.6	2,502.0
	Low	185.6	293.7	338.8	389.5	443.1	497.9	552.0	628.9	732.3	854.1	958.6	1,019.2	1,063.4

Petrol Reductions (Million DGE/GGE)	Case	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Vehicle Price Reductions	High	21.5	33.3	36.9	41.5	47.3	54.0	61.9	70.1	78.3	85.5	91.8	98.1	104.6
	Low	11.1	16.9	18.5	20.4	22.7	25.3	28.2	31.2	34.3	37.3	40.1	43.0	45.9
ZEV Industry Experience	High	-	2.1	4.5	7.1	10.0	13.0	16.1	19.3	22.7	26.2	29.7	33.3	36.9
	Low	-	1.8	3.8	6.0	8.4	10.9	13.5	16.2	19.0	21.9	24.9	27.9	30.9
Next-Generation Trucks	High	-	-	26.6	53.3	79.9	106.6	106.6	106.6	106.6	106.6	106.6	106.6	106.6
	Low	-	-	-	2.6	3.9	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2
Next-Generation Fuels	High	-	-	-	-	1.1	10.2	28.3	51.4	70.4	78.5	81.9	81.9	81.9
	Low	-	-	-	-	-	-	0.3	2.6	7.1	12.9	17.6	19.6	20.5
Total	High	21.5	35.4	68.0	101.9	138.3	183.8	212.8	247.4	278.0	296.8	310.0	320.0	330.1
	Low	11.1	18.7	22.3	29.0	35.0	41.4	47.2	55.1	65.6	77.2	87.8	95.7	102.5

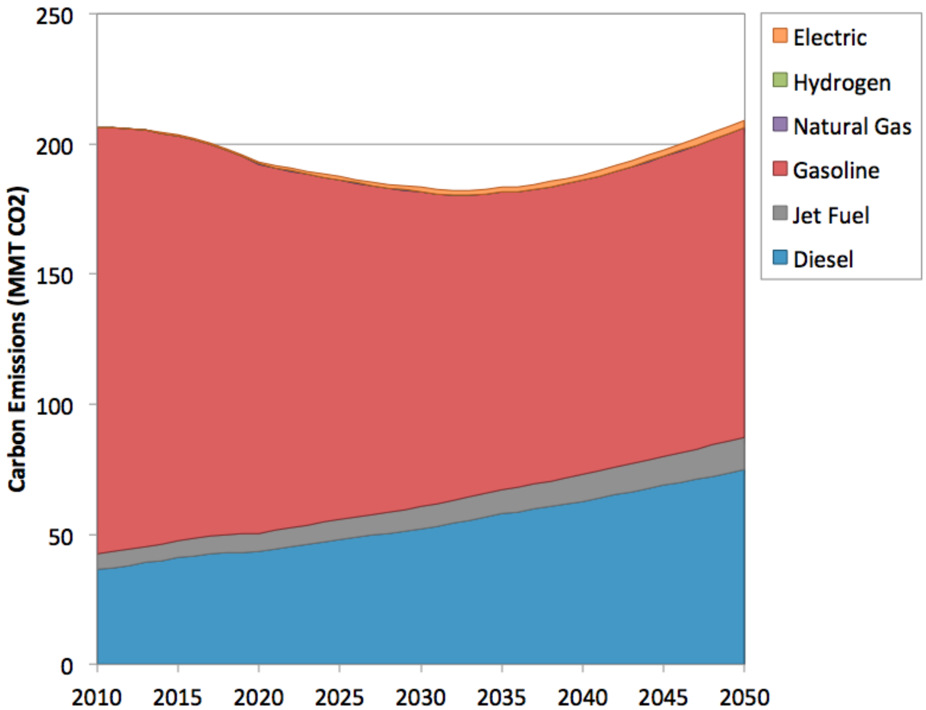
CHAPTER 4: Carbon Market Growth Requirements

Market growth benefits are based upon the trajectory of GHG reductions required to meet the long-term goal of reducing GHG emissions to 80 percent below 1990 levels by 2050. The required reduction trend is based upon the near-term trajectory of reductions (2015-2025) required to fully or partially achieve this long-term GHG goal, as depicted in the ARB *Vision for Clean Air* study. The difference between the carbon market growth requirement and the sum of GHG reductions from expected and market transformation benefits represents, roughly, the remaining gap in GHG reductions that must be closed to stay on track to meet the 2050 goal.

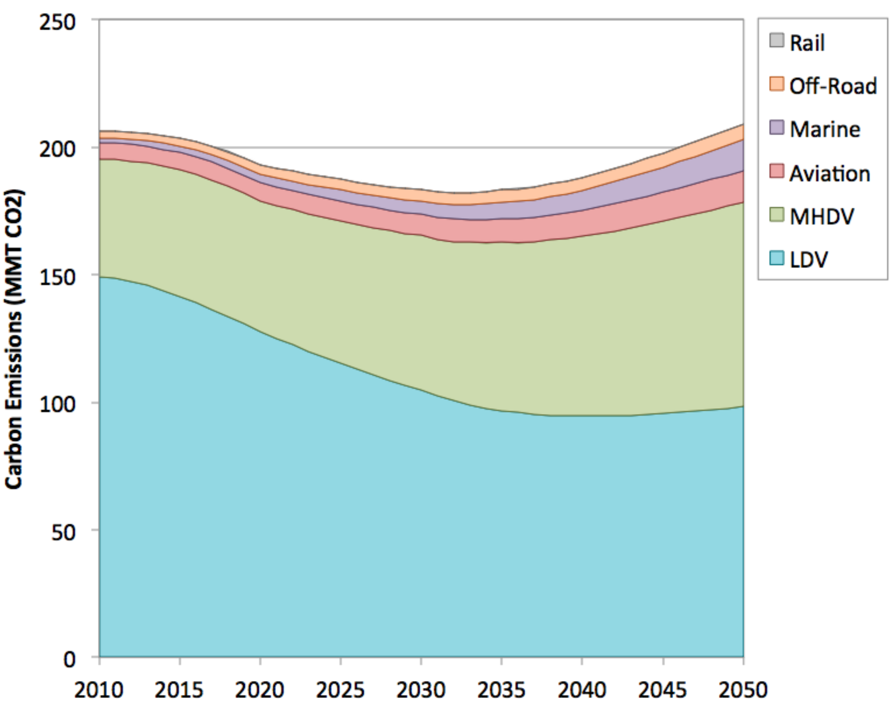
The potential for ARFVTP funding to contribute to statewide goals, the 2050 AB 32 GHG reduction goal in particular, can be quantified by comparing estimated benefits between a business-as-usual (BAU) scenario and a scenario that achieves an 80-90 percent GHG reduction in 2050 compared to 2010 emissions. The BAU scenario from the ARB Vision study is indicated in Figure 49, with GHG emissions declining to 2030 and then increasing to 2050, with total emissions in 2050 being slightly higher than in 2010. The decline through 2030 is largely due to efficiency improvements in LDVs.

An important reference for ARFVTP benefits is the path toward an 80-90 percent reduction in GHG emissions in 2050 compared to 2010 emissions. The mix of vehicle and fuel technologies relied upon in this GHG reduction scenario is unique to the ARB Vision study, but the overall magnitude of reductions indicates the magnitude of reductions required within the 2025-2030 time frame to be on a path toward deep reductions in GHG emissions in 2050. This path is indicated in terms of GHGs from fuels that continue to be used in Figure 50a, with increased use in electricity and hydrogen, primarily in the LDV sector, and significant reductions in GHG emissions from gasoline and diesel. The reductions required are indicated by the sector in which the reductions occur in Figure 50b, with LDV reductions becoming significant after 2020 and the bulk of the reductions before 2025 coming from the MHDV sector. Total reductions are on the order of 20 MMT-45 MMT CO_2 per year by 2020-2025 and reach about 80 MMT CO_2 per year by 2030. Total reductions by sector through 2050, to achieve a 90 percent reduction compared to 2010 emissions, approach 190 MMT CO_2 per year by 2050, as shown in Figure 51. Reductions in the LDV and MHDV sectors account for 45 percent and 40 percent of these reductions, respectively, while reductions in the aviation and marine sectors both account for about 6 percent of reductions by 2050. Reductions in the off-road sector account for 3 percent of overall reductions by 2050, and rail sector reductions are 0.03 percent. Figure 52 also places GHG reduction benefit estimates in context by indicating the relative magnitude of reductions from projects funded to date compared to the trajectory of the market growth GHG reductions.

Figure 49: BAU GHG Emissions From the ARB Vision Scenario Study, by Fuel (a) and Sector (b)

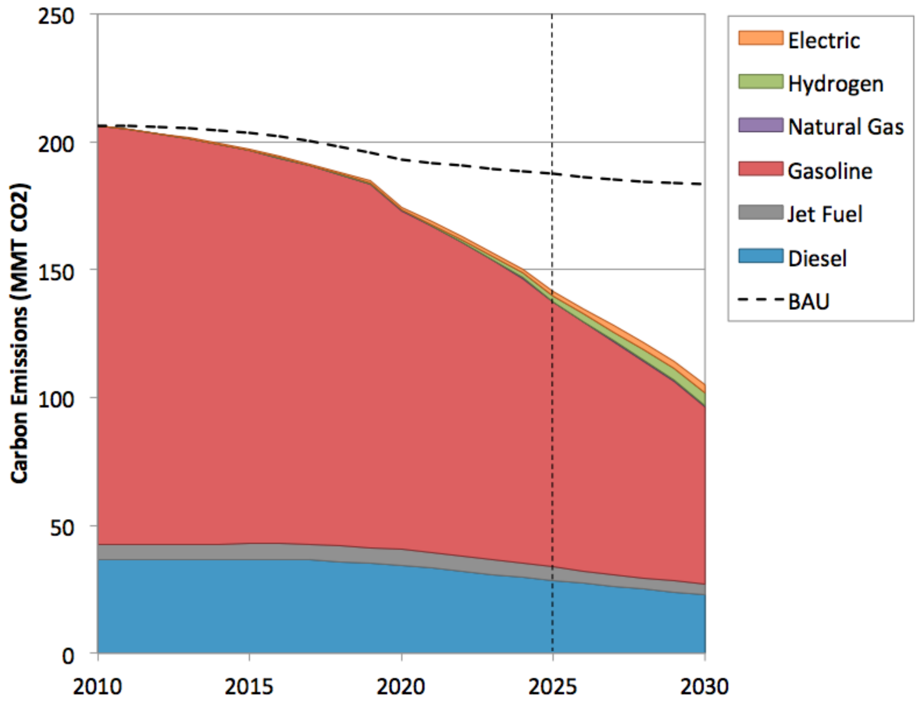


(a)

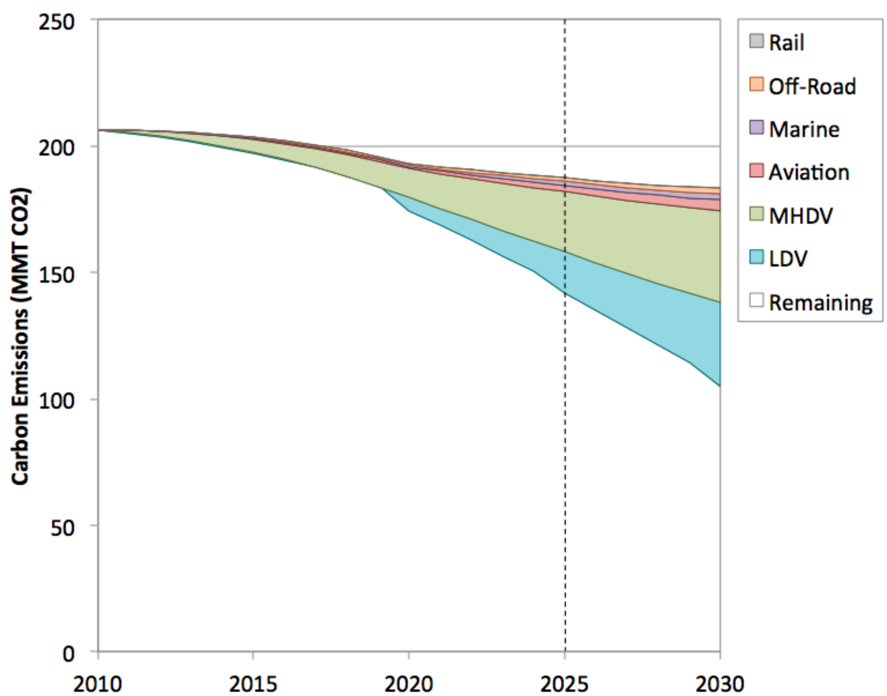


(b)

Figure 50: GHG Emission Reductions in the ARB VISION Scenario Through 2030, by Fuel Consumed (a) and by Emissions Reduced in Each Sector (b)



(a)



(b)

Figure 51: Total GHG Reductions Through 2050 by Sector

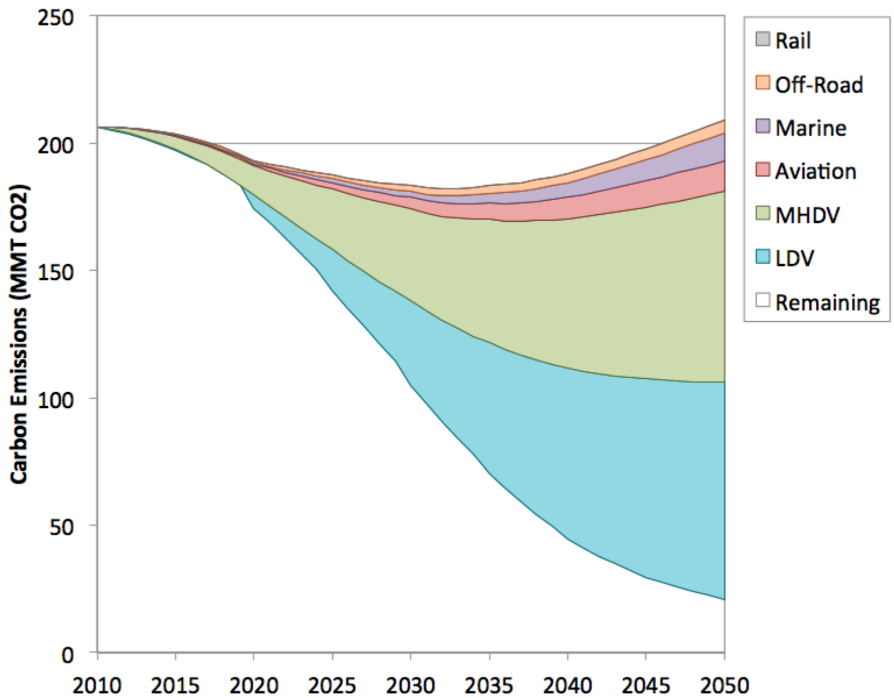
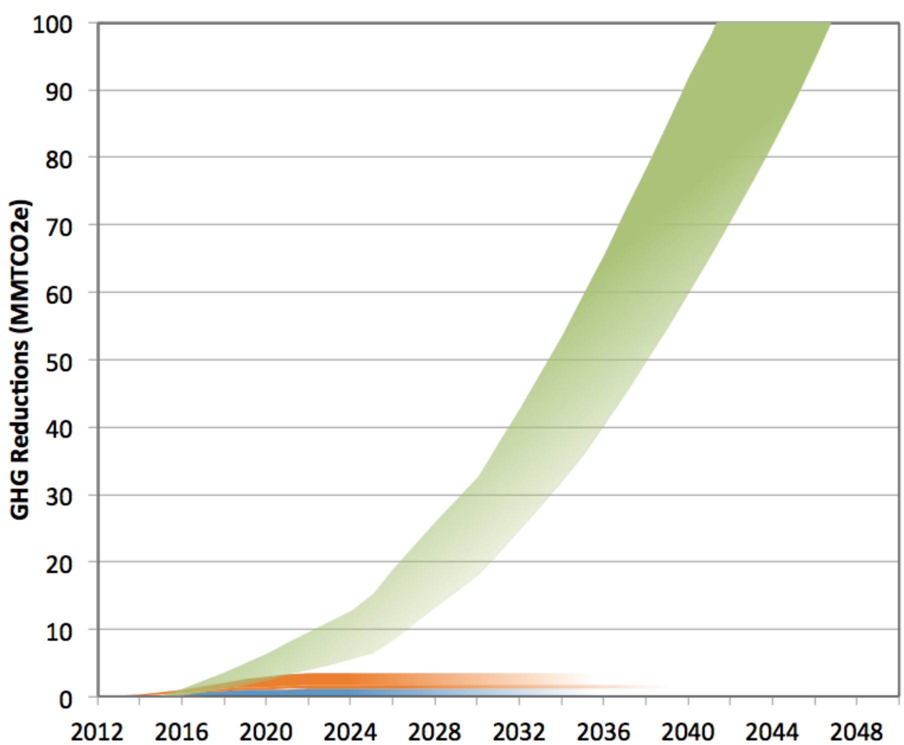


Figure 52: Near- and Long-Term Perspective on GHG Reductions



CHAPTER 5: Summary and Recommendations

This chapter summarizes benefit estimates and reviews key recommendations to improve future benefit estimation efforts for ARFVTP.

5.1 Summary of Benefit Estimation Results

This report focuses on two types of benefits resulting from ARFVTP activities − expected benefits, based upon data collected at the project level, and market transformation benefits, based upon estimates of changes in market conditions that would lead to accelerated market adoption of advanced vehicle and fuel technologies. Single-value estimates are made for expected benefits, and high and low estimates are made for market transformation benefits. A third category of benefits, market growth benefits, is determined based upon market growth trends required to approach long-term GHG reduction goals, such as an 80 percent reduction in GHG emissions by 2050.

The GHG and petroleum fuel reductions associated with expected benefits are indicated in Tables 37 and 38. As shown, GHG reductions are split among fuel infrastructure, vehicles, and fuel production projects, increasing over time to about 1.6 $MMTCO_2e$ by 2025. Roughly half of petroleum fuel reductions are from projects within the fueling infrastructure category, and overall reductions increase over time to roughly 225 million gallons of gasoline and diesel fuel by 2025. Reductions in the fueling infrastructure and fuel production categories are relatively flat after around 2018-2020, while reductions in the vehicle category continue to increase out to 2025. Figures 53 and 54 represent the high and low market transformation GHG reduction benefits relative to expected and market growth benefit results. As indicated, the high market transformation reductions are roughly equal to total expected benefit GHG reductions, while market growth reductions rapidly exceed the sum of expected and market transformation benefits after about 2020.

Unlike the market growth projection estimates in the Energy Commission's 2011 Benefits Report, market transformation benefits are based only upon the potential market impacts of ARFVTP activities funded to date and do not include benefits that would accrue due to additional market growth from either continued ARFVTP support or competitive market dynamics. Therefore, the gap between the sum of expected benefits and market transformation benefits and the future trajectory of market growth benefits represent the additional market success required to keep on track toward meeting long-term GHG reduction goals.

Table 37: Summary of GHG Reductions for All Benefit Categories

Benefit Category	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Expected Benefits													
Fueling Infrastructure	0.0	21.6	63.6	134.2	258.1	368.8	453.7	464.9	469.6	469.6	469.6	469.6	469.6
Vehicles	71.9	85.4	84.1	97.6	148.2	238.0	352.5	461.6	562.6	651.6	730.9	800.0	859.4
Fuel Production	-	0.1	39.1	114.7	226.9	334.4	389.6	416.7	416.7	416.7	416.7	416.7	416.7
TOTAL	71.9	107.1	186.8	346.5	633.2	941.2	1,196	1,343	1,449	1,538	1,617	1,686	1,746
Market Transformation Benefits													
High													
Vehicle Price Reductions	181.2	279.1	309.8	348.7	394.0	443.9	499.8	563.8	614.9	651.8	675.8	698.6	720.4
ZEV Industry Experience	-	16.0	34.2	54.4	76.2	99.0	122.4	145.7	166.6	187.3	207.5	227.0	245.5
Next Generation Trucks	-	-	123.6	247.2	370.8	494.5	494.5	494.5	494.5	494.5	494.5	494.5	494.5
Next Generation Fuels	-	-	-	-	9.7	105.3	341.6	659.7	919	1,009	1,042	1,042	1,042
Total	181.2	295.1	467.6	650.3	850.7	1,143	1,458	1,864	2,195	2,343	2,419	2,462	2,502
Low													
Vehicle Price Reductions	185.6	280.3	304.4	332.3	361.9	391.9	424.0	457.5	484.3	509.2	532.0	553.7	574.2
ZEV Industry Experience	-	13.4	28.6	45.5	63.8	82.9	102.5	122.0	139.5	156.8	173.8	190.1	205.6
Next Generation Trucks	-	-	5.79	11.57	17.36	23.14	23.14	23.14	23.14	23.14	23.14	23.14	23.14
Next Generation Fuels	-	-	-	-	-	-	2.4	26.3	85.4	164.9	229.7	252.2	260.4
Total	185.6	293.7	338.8	389.5	443.1	497.9	552.0	628.9	732.3	854.1	958.6	1,019	1,063
Required Carbon Market Growth													
High	-	-	-	1,084	2,252	3,543	4,918	6,397	7,902	9,461	11,014	12,614	15,189
Low	-	-	-	-	487.6	1,029	1,652	2,333	3,081	3,842	4,650	5,481	6,375

Table 38: Summary of Petroleum Fuel Reductions for All Benefit Categories

Benefit Category	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Expected Benefits													
Fueling Infrastructure	0.0	3.8	16.4	33.8	56.3	72.3	83.4	85.4	86.0	86.0	86.0	86.0	86.0
Vehicles	17.9	21.3	20.7	21.4	26.4	36.4	49.6	62.4	74.2	84.4	93.6	101.8	109.1
Fuel Production	-	0.0	3.5	10.4	21.2	32.1	38.0	41.0	41.0	41.0	41.0	41.0	41.0
TOTAL	17.9	25.1	40.7	65.6	103.9	140.9	171.1	188.8	201.2	211.4	220.7	228.8	236.1
Market Transformation Benefits													
High													
Vehicle Price Reductions	21.5	33.3	36.9	41.5	47.3	54.0	61.9	70.1	78.3	85.5	91.8	98.1	104.6
ZEV Industry Experience	-	2.1	4.5	7.1	10.0	13.0	16.1	19.3	22.7	26.2	29.7	33.3	36.9
Next Generation Trucks	-	-	26.6	53.3	79.9	106.6	106.6	106.6	106.6	106.6	106.6	106.6	106.6
Next Generation Fuels	-	-	-	-	1.1	10.2	28.3	51.4	70.4	78.5	81.9	81.9	81.9
Total	21.5	35.4	68.0	101.9	138.3	183.8	212.8	247.4	278.0	296.8	310.0	320.0	330.1
Low													
Vehicle Price Reductions	11.1	16.9	18.5	20.4	22.7	25.3	28.2	31.2	34.3	37.3	40.1	43.0	45.9
ZEV Industry Experience	-	1.8	3.8	6.0	8.4	10.9	13.5	16.2	19.0	21.9	24.9	27.9	30.9
Next Generation Trucks	-	-	-	2.6	3.9	5.2	5.2	5.2	5.2	5.2	5.2	5.2	5.2
Next Generation Fuels	-	-	-	-	-	-	0.3	2.6	7.1	12.9	17.6	19.6	20.5
Total	11.1	18.7	22.3	29.0	35.0	41.4	47.2	55.1	65.6	77.2	87.8	95.7	102.5
Required Carbon Market Growth													
High	-	-	-	113.4	225.7	337.7	445.6	665.4	901.4	1,151	1,417	1,695	1,959
Low	-	-	-	-	44.0	88.4	129.9	237.2	358.4	492.1	643.0	804.2	957.3

Figure 53: GHG Reductions for Expected and Market Transformation Benefits

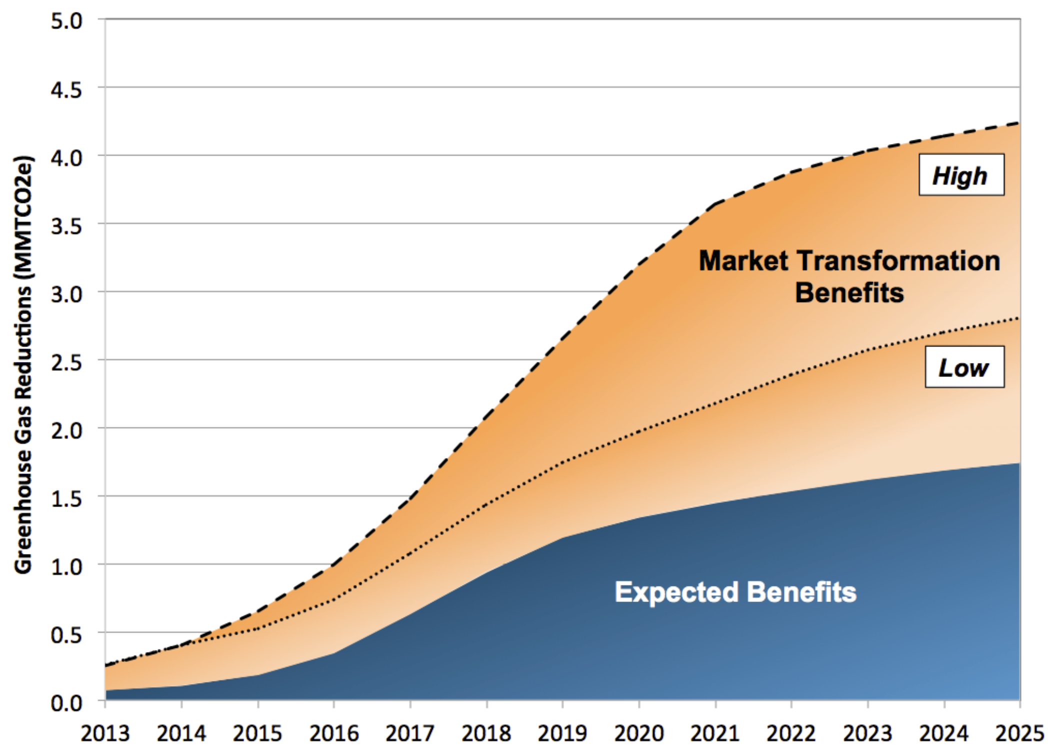
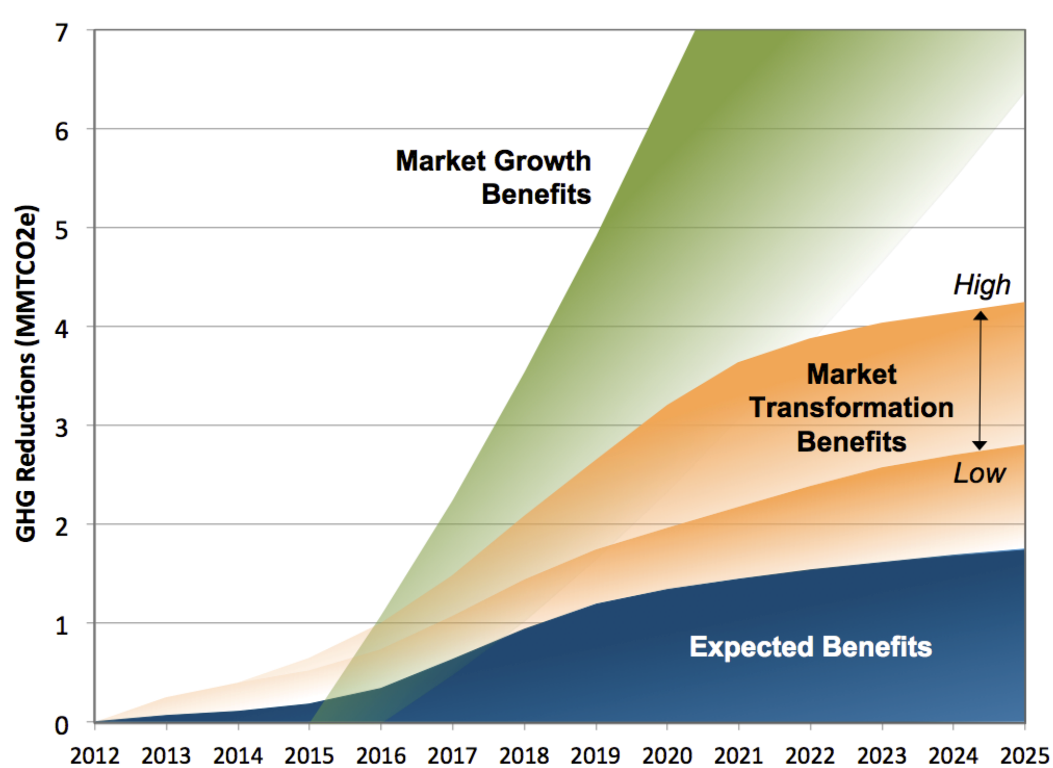


Figure 54: GHG Reductions for Three Benefit Categories



5.2 Recommendations to Improve Benefit Estimation Methods

Future work to estimate benefits associated with ARFVTP activities can be improved by integrating additional data at the project level and by applying enhanced and integrated market assessment methods. Each of the following methodological improvements should be considered for subsequent analyses:

- Collect and integrate data on technology-specific deployment effectiveness metrics.
- Project evaluation metrics as they might be realized under market success conditions.
- Explicitly model competitive dynamics between advanced and incumbent technologies.
- Integrate value of station availability into vehicle choice modeling.

The present analysis expands and improves upon past ARFVTP benefit estimate efforts but is limited by available project-level data and indicators of market success. As additional market experience accumulates and more data on ARFVTP project become available, enhancements to this analytic framework will result in more complete and rigorous benefit estimates.

Acronyms

Alternative and Renewable Fuel and Vehicle Technology Program (ARFVTP)

Alternative Fuel Vehicle (AFV)

Argonne National Laboratory (ANL)

Average (AVG)

Battery electric vehicle (BEV)

California (CA)

California reformulated gasoline blendstock for oxygenate blending (CARBOB)

Carbon capture and storage (CCS)

Compressed natural gas (CNG)

Carbon monoxide (CO)

Carbon dioxide equivalent (CO_2eq)

Dry distillers grain soluble (DDGS)

Diesel gallon equivalent (DGE)

Energy economy ratio (EER)

Fischer-Tropsch (FT)

Gasoline gallon equivalent (GGE)

Greenhouse gas (GHG)

Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET)

Gross vehicle weight (GVW)

Hydrogen (H2)

Low Carbon Fuel Standard (LCFS)

Liquid natural gas (LNG)

Land-use change (LUC)

Liquid petroleum gas (LPG)

Municipal solid waste (MSW)

Natural gas (NG)

Nitrous oxides (NO_x)

Plug-in hybrid electric vehicle (PHEV)

Particulate matter (PM)

Renewable Diesel (RD)

Research and development (R&D)

Sulfur oxides (SO_x)

Short rotation woody crops (SRWC)

Ultra-low-sulfur diesel (ULSD)

Vehicle miles traveled (VMT)

Volatile organic compounds (VOC)

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APPENDIX A:
Displacement Calculations

Expected benefits are determined with reference to the vehicles and fuels being displaced by new alternative and renewable technologies. The VISION model of fleet dynamics is used to calculate displaced petroleum fuel use for vehicles introduced in different years. The following factors must be determined in the baseline scenario to consistently estimate future displacements:

- Year of vehicle introduction
- Vehicle fuel economy or fuel consumption (assumed constant over lifetime)
- Vehicle miles traveled (VMT) per year
- Vehicle scrappage rate (probability of retirement as a function of age)

The VISION model accounts for each of these factors over time, including the attributes of new vehicles sold each year and the escalation of yearly VMT per vehicle to match estimates of total VMT of all vehicles in California. As vehicles age, some fraction is retired, and yearly VMT decline. The introduction of more efficient vehicles into the fleet results in less fuel consumption as older vehicles are scrapped and newer vehicles account for a greater percentage of total fleet VMT. Fuel use and emissions are determined as a function of VMT driven and the fuel economy and emissions rate of vehicles of a given vintage. The general equation for fuel consumption is:

$$Q_{i,t} = \sum_{i,t} \frac{VMT_{i,t}}{FE_{i,t}} N_{i,t}$$

where $Q_{i,t}$ is total fuel use for a given number of vehicles ($N_{i,t}$) of a particular age (i) and type (t), driven a given number of yearly VMT and with a given fuel economy (FE). Emission rates are determined as an emissions factor multiplied by total fuel consumption or total miles driven.

Displacement calculations for vehicles are dependent upon the average fuel economy of the new vehicles that would have been introduced in any given year. This is expected in Figure A-1, which indicates total VMT, the number of vehicles, and total fuel consumption change over time for a nominal fleet of 1,000 passenger cars. Fuel economy (mpg) and the inverse measure, fuel consumption (gallons per 100 miles), are assumed to be constant over time, with units indicated on the left-hand axis. In this example, the 1,000 cars have an on-road fuel economy of 28.5 mpg (solid blue line), which is equivalent to a fuel consumption rate of 3.5 gal/100 miles (dashed blue line). VMT per passenger car are also indicated on the left-hand axis; they decay with vehicle age, starting at 21,331 miles per year in the first year of operation and declining to roughly 4,800 miles per year after 22 years of operation (blue line with white circles). The number of passenger cars remaining in operation as the nominal fleet of 1,000 passenger cars ages—with a percentage of remaining passenger cars being scrapped in any given year—is indicated on the right-hand axis (orange line with triangles). The 1,000 vehicles in operation during the first year decline to about 500 vehicles after 15 years of operation and to 125 vehicles after 22 years of operation.

Following the general equation indicated above, total fleet fuel use is calculated as a function of the total number of cars operating in a given year multiplied by the average VMT per car and divided by fuel economy (or multiplied by fuel consumption). Units for total fleet fuel use are indicated on the right hand axis and decline from about 750,000 gallons in the first year of operation down to about 20,000 gallons per year after the fleet has aged 22 years (orange line with solid circles). Examples of values used in these calculations for each factor and resulting fleet fuel use are indicated for the first, fifth, and twentieth year of fleet operation in Table A-1.

Figure A-1: Nominal Fuel Use by Vehicle Age for 1,000 Cars

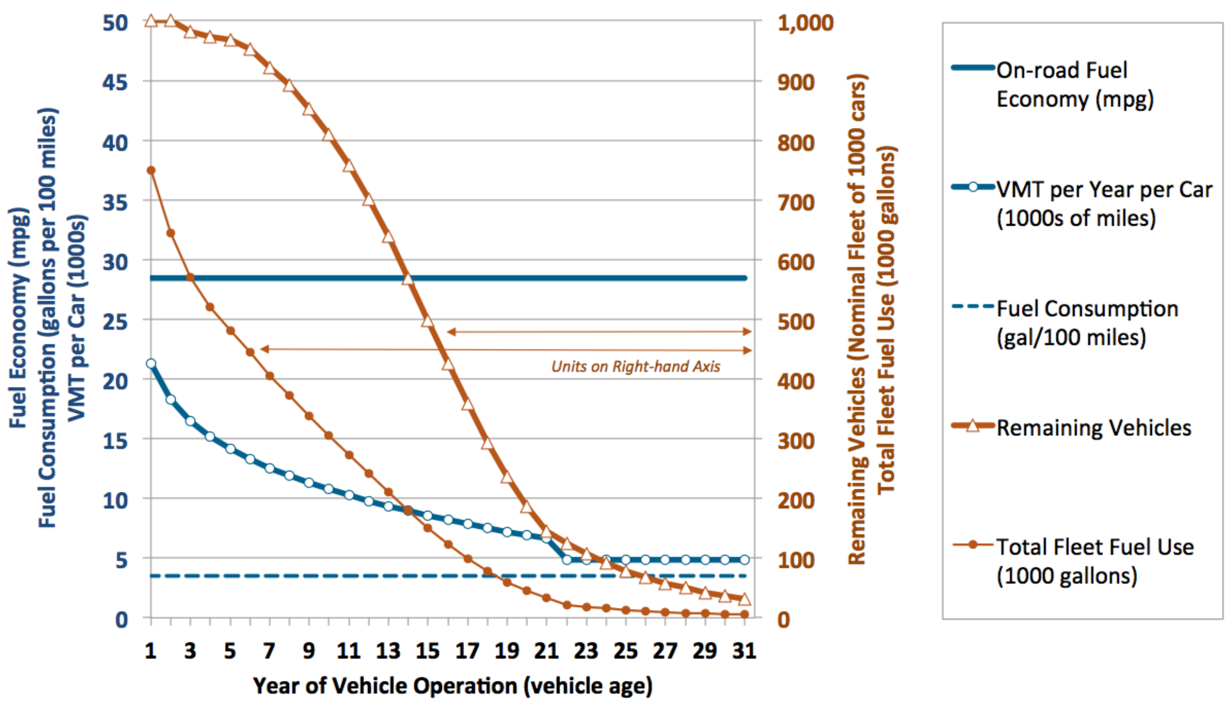


Table A-1: Example Fleet Fuel Use Calculations for Nominal Fleet of 1,000 Cars

Year of Operation	Number of Cars	Average VMT	Fuel Economy (mpg)	Fleet Fuel Use (1000s gal)
1st year	1000	21,331	28.4	750
5th year	953	13,265	28.4	444
20th year	145	6,663	28.4	34

By articulating projected fuel use over the life of particular vehicle types, annual displaced fuel use can be determined consistently across multiple types of alternative and renewable fuels and vehicles. In the nominal fleet example above, more than 30 years of fleet operation over roughly

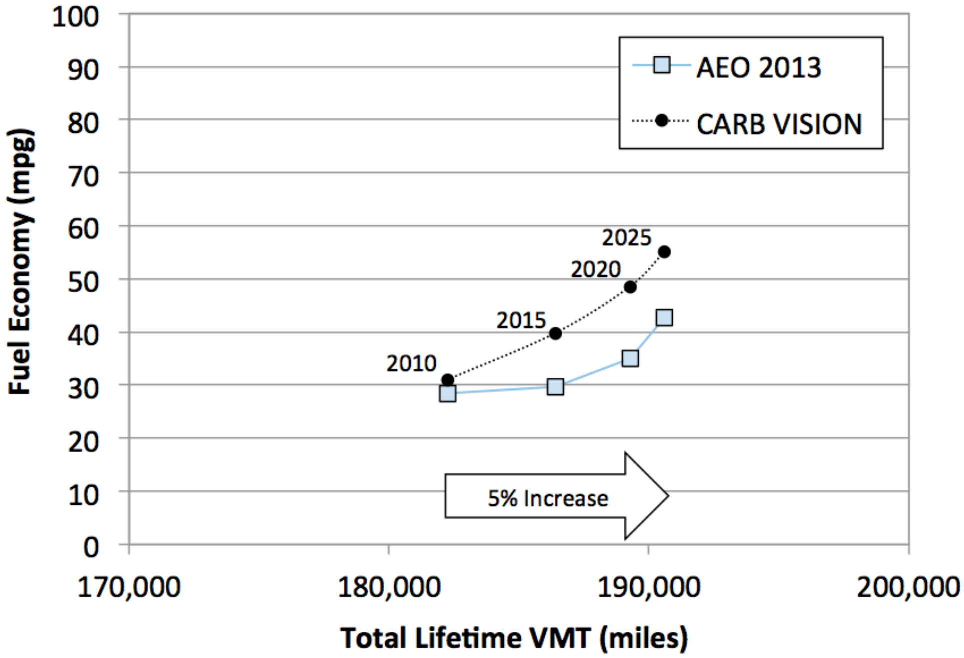
183,000 miles would be driven, and 6,000 gallons of petroleum fuel would be consumed for each passenger car introduced in the first year of fleet operation. Given the scrappage rates used in VISION, only 3 percent of the vehicles would still be in operation after 30 years, and these remaining vehicles would consume fuel at a rate equal to 0.7 percent of fuel use during the first year of fleet operation due to the decline in yearly VMT and vehicle scrappage.

To account for new vehicles and fuels introduced due to support provided by ARFVTP, it is assumed that new vehicle fuel economy and lifetime VMT projections correspond to a BAU reference scenario. This is a key assumption. Unlike programs or policies designed to influence markets over the long term, such as the ZEV mandate or LCFS, the ARFVTP is influencing future trends in California's transportation sector in the near term. Consideration of how these influences might propagate through a BAU reference scenario is an appropriate frame of reference for understanding the benefits of decisions made in the near term. If, in contrast, ARFVTP benefits were determined with reference to a low-carbon success scenario, displacement calculations would suggest fewer benefits due to projected increases in fuel economy, reductions in fuel carbon intensity, and lower VMT. Calculations that account for diminishing returns over time are more appropriate for long-term policy or program evaluations.

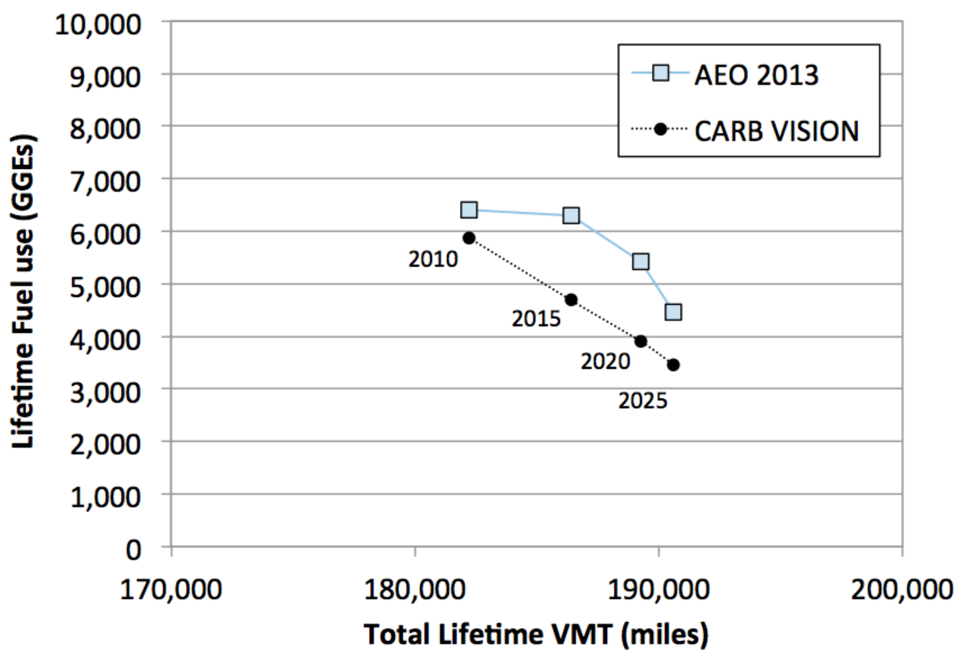
The significance of the assumption that benefits are calculated based upon a BAU reference scenario can be clarified by comparing BAU scenario trends to trends from the ARB VISION scenario. As an example, Figure A-2 indicates trends in passenger car fuel economy and total lifetime fuel consumption with respect to total lifetime VMT for introduction years of 2010, 2015, 2020, and 2025. Figure A-2 indicates new passenger car fuel economy in the AEO 2013 scenario increasing from 28.5 mpg in 2010 to 42.6 mpg in 2025, while total lifetime VMT increases by about 5 percent or from 182,000 to 190,000 miles. In contrast, new passenger car fuel economy increases to 55 mpg in the ARB VISION scenario. The resulting change in lifetime fuel consumption is indicated in Figure A-2b, with new passenger vehicles introduced in 2015 consuming 6,300 gges in the BAU scenario and 4,700 gges in the ARB VISION scenario, a reduction of 26 percent.

Heating values for different fuels are indicated in Table A-2.

Figure A-2: New Passenger Car Fuel Economy by Year (a) and Lifetime Fuel Use for 1,000 Passenger Cars (b) as a Function of Lifetime VMT for Fuel Economies From AEO 2013 and ARB VISION Scenarios



(a)



(b)

Table A-2: Fuel Heating Values

Conversions Original Energy Type	Liquid (LHV) Btu/gal	Gaseous (LHV) Btu/scf
CA reformulated gasoline	109,772	
U.S. conventional diesel	128,450	
Ethanol	76,330	
Fischer-Tropsch diesel (FTD)	122,800	
Methyl ester (biodiesel, BD)	119,550	
Renewable Diesel I (SuperCetane)	117,059	
Natural gas		930
Gaseous hydrogen		282

APPENDIX B:
Polk Vehicle Registration Data

NREL maintains vehicles in operation (VIO) data acquired from R.L. Polk ("Polk Data") for calendar years (CYs) 2006 through 2012. The contractual agreement between NREL and Polk allows the data to be embedded in a model and used for analysis. The summarized or aggregated results of the modeling or analysis based upon Polk data may be published or shared with a third party, but the raw data cannot be shared in any form.

Polk data are a snapshot of all registered vehicles in operation (assumed on the road) for a particular survey year (calendar year). Survey years end January 1. So, for example, 2012 Polk data represent all registered vehicles in operation as of January 1, 2013. Polk data are gathered from the Department of Motor Vehicles (DMV) of each state, and the data may be limited in some manner depending upon the entity or process of collecting data in each state.

Below are some additional characteristics of the Polk data:

- Polk cross-references vehicle identification numbers (VIN) within DMV data to improve accuracy.
- Polk data do not include complete data on some alternative fuel vehicles such as CNG or LPG because many of these vehicles are after-market conversions rather than original equipment manufacturer (OEM) vehicles. After-market conversions would not be reflected in the VIN. Vehicle counts for CNG and LPG are therefore short of the total number of actual vehicles on the road.
    - EIA surveys two entities (as required by Epact): OEMs and conversions companies. This survey is done for a limited number of fleets and is a means of estimating total AFVs on the road each year. Data are available at http://www.eia.gov/renewable/afv/index.cfm
- Due to staggered model year introductions, there will inevitably be a number of later model year (for example, 2013MY) vehicles in each year's data (e.g. 2012MY). This overlap is common for data in all years. However, it is generally reasonable to assume that a particular model year vehicle was sold and registered in the same calendar year. For example, 2012MY vehicles are generally sold in 2012CY.
- Polk data has 11 fuel categories. They are self-explanatory except for the "CONVERTIBLE" category, which indicates that the OEM vehicle has been prepped to run on an alternative fuel (for example, converted to run on CNG or LPG in an after-market conversion) may actually be running on conventional fuel in operation.

Resolving Categories of Vehicles in the Internal NREL Database

Polk does not differentiate between a conventional HEV and a PHEV; both are in the category of "ELECTRIC AND GAS HYBRID." The discrepancy between HEVs and PHEVs can be resolved only if a particular vehicle as a unique identifier outside the fuel category, such as the "Prius Plug-in."

- Chevy Volts are PHEVs but are categorized as “ELECTRIC AND GAS HYBRIDS”. However, due to the unique name, Volts have been separated out into a PHEV category within the internal NREL database.
- Fisker Automotive Karmas are categorized as “ELECTRIC” but are included in the PHEV category within the internal NREL database.
- The Ford Fusion and C-MAX vehicles are manufactured as both HEV and PHEV powertrains but are not differentiable within the Polk database. Within the internal NREL database, it is assumed that the Fusion and C-MAX counts are 9.9 percent and 14.0 percent PHEVs, respectively. The data underlying these estimates are provided in Table B1 below.
- Neighborhood electric vehicles (NEVs) are counted as regular “ELECTRIC” vehicles in the Polk database.

Table B-1: Sales of HEVs and PHEVs Within Ford Fusion and C-Max Sales.

Month	Ford Fusion Energi[1]	Ford Fusion Hybrid[1]	Total Fusion Sales[2]	PHEV Take Rate	Ford C-Max Energi[1]	Ford C-Max Hybrid[1]	Total Ford C-Max Sales[2]	PHEV Take Rate
Jan-12	0	611	13614		0	0	0	0
Feb-12	0	1110	21773		0	0	0	0
Mar-12	0	1009	28562		0	0	0	0
Apr-12	0	778	21610		0	0	0	0
May-12	0	683	26857		0	0	0	0
Jun-12	0	797	24433		0	0	0	0
Jul-12	0	1109	23326		0	0	0	0
Aug-12	0	1071	21690		0	0	0	0
Sep-12	0	898	19736		0	969	969	0
Oct-12	0	956	18320		144	3038	3182	4.5%
Nov-12	0	1838	18312		1259	3589	4848	26.0%
Dec-12	0	3244	19283		971	3339	4310	22.5%
Jan-13	0	3043	22399		338	2387	2725	12.4%
Feb-13	119	3806	27875	3.0%	334	2849	3183	10.5%
Mar-13	295	3417	30284	7.9%	494	3275	3769	13.1%
Apr-13	364	3625	26722	9.1%	411	3197	3608	11.4%
May-13	416	3335	29553	11.1%	450	3261	3711	12.1%
Jun-13	390	3057	34313	11.3%	455	2889	3344	13.6%
Jul-13	407	2914	20522	12.3%	433	2267	2700	16.0%

NOTES:

1 Source: HybridCARS.com; Hybrid Market Dashboard, http://www.hybridcars.com/market-dashboard

2 Source: Automotive news data center; US Light-vehicle Sales by Nameplate, http://www.autonews.com/apps/pbcs.dll/search?Category=DATACENTER01archive&SearchCategory=DATACENTER&SearchProfile=1061&noblankcheck=1&ProfileName=U.S. Light-Vehicle Sales by Nameplate#axzz2cS1cCSDe

3 Assumed mix of on-road Fusion PHEVs is 9.9%, based upon average PHEV Take Rate from March through June 2013. Assumed mix of on-road C-Max PHEVs is 14.0%, based upon average PHEV Take Rate from December 2012 through July 2013.

APPENDIX C:
Criteria Emission Summary

Fuel Groups - ROG Net Reductions (tonnes)

Fuel Class		2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Biodiesel		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NG		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LPG		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Electric		0	0	0	1	3	7	15	27	43	60	75	90	104	116	128
Ethanol		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FT Diesel		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen		0	0	0	0	0	0	1	2	3	3	3	3	3	4	4
RD		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total		0	0	0	1	3	7	16	29	46	63	79	93	107	120	131

Project Sub-Class Groups - ROG Net Reductions (tonnes)

Project Class	Project Sub-Class	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Fueling Infrastructure	Biodiesel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fueling Infrastructure	Natural and Renewable Gas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fueling Infrastructure	Electric Chargers	0	0.00	0.00	1.75	4.79	7.82	8.96	8.87	8.61	8.25	7.86	7.36	6.85	6.34	5.83
Fueling Infrastructure	E85 Ethanol	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fueling Infrastructure	Hydrogen	0	0.00	0.00	0.02	0.28	0.66	1.16	1.45	1.64	1.60	1.53	1.43	1.33	1.23	1.13
Vehicle	Light Duty BEVs and PHEVs	0	0.00	0.00	0.00	0.00	0.00	0.48	0.58	0.56	0.54	0.52	0.49	0.46	0.43	0.40
Vehicle	Electric Commercial Trucks	0	0.00	0.00	0.00	0.00	0.11	0.13	0.13	0.12	0.12	0.11	0.11	0.10	0.09	0.08
Vehicle	NG Commercial Trucks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vehicle	LPG Commercial Trucks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vehicle	Manufacturing	0	0.00	0.00	0.00	0.13	3.09	6.58	9.39	9.26	8.87	8.44	7.91	7.36	6.81	6.27
Fueling Production	Biomethane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fueling Production	Diesel Substitute	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fueling Production	Gasoline Substitute	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Total		0	0.0	0.0	1.8	5.2	11.7	17.3	20.4	20.2	19.4	18.5	17.3	16.1	14.9	13.7

Project Groups - ROG Net Reductions (tonnes)

Project Class		2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Fuel Production		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fueling Infrastructure		0	0	0	1	3	5	7	8	9	10	11	11	12	12	12
Vehicle		0	0	0	0	0	3	9	21	37	53	68	82	95	108	119
Total		0	0	0	1	3	7	16	29	46	63	79	93	107	120	131

Fuel Groups - NOx Net Reductions (tonnes)

Fuel Class		2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Biodiesel		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NG		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LPG		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Electric		0	0	0	2	5	12	24	45	72	56	70	84	97	108	68
Ethanol		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FT Diesel		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen		0	0	0	0	0	1	2	4	5	3	3	3	3	3	2
RD		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total		0	0	0	2	5	12	27	49	77	58	73	87	100	112	70

Project Sub-Class Groups - NOx Net Reductions (tonnes)

Project Class	Project Sub-Class	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Fueling Infrastructure	Biodiesel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fueling Infrastructure	Natural and Renewable Gas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fueling Infrastructure	Electric Chargers	0	0.00	0.00	2.23	6.10	9.96	11.40	11.28	10.96	10.50	10.00	9.37	8.72	8.07	7.42
Fueling Infrastructure	E85 Ethanol	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fueling Infrastructure	Hydrogen	0	0.00	0.00	0.02	0.35	0.85	1.48	1.85	2.08	2.04	1.94	1.82	1.69	1.57	1.44
Vehicle	Light Duty BEVs and PHEVs	0	0.00	0.00	0.00	0.00	0.00	0.60	0.71	0.69	0.67	0.64	0.61	0.57	0.53	0.49
Vehicle	Electric Commercial Trucks	0	0.00	0.00	0.00	0.00	0.26	0.31	0.30	0.29	0.27	0.26	0.24	0.23	0.21	0.19
Vehicle	NG Commercial Trucks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vehicle	LPG Commercial Trucks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vehicle	Manufacturing	0	0.00	0.00	0.00	0.17	3.93	8.38	11.95	11.79	11.29	10.75	10.07	9.37	8.67	7.98

Fueling Production	Biomethane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fueling Production	Diesel Substitute	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fueling Production	Gasoline Substitute	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total		0	0	0	2	7	15	22	26	26	25	24	22	21	19	18

Project Groups - NOx Net Reductions (tonnes)

Project Class		2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Fuel Production		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fueling Infrastructure		0	0	0	2	5	8	11	13	16	10	10	11	11	11	7
Vehicle		0	0	0	0	0	4	16	36	62	49	63	76	89	100	63
Total		0	0	0	2	5	12	27	49	77	58	73	87	100	112	70

Fuel Groups - PM2.5 Net Reductions (tonnes)

Fuel Class		2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Biodiesel		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
NG		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
LPG		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Electric		0	0	0	1	3	7	15	27	43	60	75	90	104	116	121
Ethanol		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
FT Diesel		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrogen		0	0	0	0	0	0	1	2	3	3	3	3	3	4	3
RD		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total		0	0	0	1	3	7	16	29	46	63	79	93	107	120	125

Project Sub-Class Groups - PM2.5 Net Reductions (tonnes)

Project Class	Project Sub-Class	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Fueling Infrastructure	Biodiesel	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fueling Infrastructure	Natural and Renewable Gas	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fueling Infrastructure	Electric Chargers	0	0.00	0.00	0.29	0.78	1.28	1.47	1.45	1.41	1.35	1.29	1.20	1.12	1.04	0.95
Fueling Infrastructure	E85 Ethanol	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fueling Infrastructure	Hydrogen	0	0.00	0.00	0.00	0.05	0.11	0.19	0.24	0.27	0.26	0.25	0.23	0.22	0.20	0.19

Vehicle	Light Duty BEVs and PHEVs	0	0.00	0.00	0.00	0.00	0.00	0.06	0.07	0.07	0.07	0.06	0.06	0.06	0.05	0.05
Vehicle	Electric Commercial Trucks	0	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
Vehicle	NG Commercial Trucks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vehicle	LPG Commercial Trucks	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Vehicle	Manufacturing	0	0.00	0.00	0.00	0.02	0.51	1.08	1.54	1.52	1.45	1.38	1.29	1.20	1.11	1.03
Fueling Production	Biomethane	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fueling Production	Diesel Substitute	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fueling Production	Gasoline Substitute	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Total		0	0	0	0	1	2	3	3	3	3	3	3	3	2	2

Project Groups - PM2.5 Net Reductions (tonnes)

Project Class		2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025
Fuel Production		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Fueling Infrastructure		0	0	0	1	3	5	7	8	9	10	11	11	12	12	12
Vehicle		0	0	0	0	0	3	9	21	37	53	68	82	95	108	113
Total		0	0	0	1	3	7	16	29	46	63	79	93	107	120	125