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Effectiveness of the California Light Duty Vehicle Regulations As Compared to Federal Regulations

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Abstract

This study compares the protectiveness of California's current light-duty vehicle emission regulations (the "California Program") to analogous federal regulations (the "Federal Program") promulgated by the U.S. Environmental Protection Agency ("U.S. EPA"). The California Program and the Federal Program specify similar requirements for exhaust and evaporative emissions. There are two primary differences between the California Program and the Federal Program: (1) California's Zero Emission Vehicle ("ZEV") Standards ("ZEV Standards" or "ZEV Mandate"), which require that manufacturers produce and sell specified amounts of vehicles certified to specific standards for air pollutants (the Federal Program does not set ZEV Standards); and (2) California's greenhouse gas ("GHG") exhaust emission standards ("GHG Standards"), which establish limits on GHG emission rates for new vehicles in accordance with California Assembly Bill 1493 ("AB 1493"). To evaluate the ZEV and GHG Standards, we rely on documentation developed by California Air Resources Board ("CARB") staff describing the specific requirements and implementation processes of the Standards. Thus, for the purposes of this study, the California Program includes the exhaust and evaporative emission standards, the ZEV Standards, and the GHG Standards. In contrast, the Federal Program includes only the exhaust and evaporative emission standards.

We analyze the combined effects of the ZEV and GHG standards, along with all other provisions of the California Program, on criteria pollutant emissions from light-duty vehicles in California over the period from 2009 to 2023. Emissions under the California Program are compared to a fleet and emissions "baseline" that reflects implementation of the Federal Program. Determining the effects of the California Program relative to the Federal Program is important, as one of the necessary conditions for the U.S. EPA to grant a waiver to California to adopt different vehicle emission standards—under Section 209 of the Clean Air Act—is that the California standards be "… in the aggregate at least as protective of public health as applicable Federal standards."

Our results indicate that the California Program, in the aggregate, is less protective of public health than the Federal Program with respect to emissions of ozone precursors and several other criteria pollutants.

The emissions results in this report are based upon models that evaluate, among other things, the effects of the California Program on the California motor vehicle fleet and on vehicle miles traveled ("VMT") by the fleet relative to conditions that would exist with the Federal Program in effect in California. The modeling begins with detailed assessments of ZEV-credit-generating technologies and GHG-reducing technologies that could be applied to various types of motor vehicles to achieve compliance with the California Program. These assessments result in estimates of the impacts of the California Program on costs, prices, emission rates, and other attributes (e.g., fuel economy) of *new* vehicles sold in each year from 2009 to 2023. These estimates are based upon a detailed model of the markets for new motor vehicles in California. In performing these assessments, we have used conservative assumptions that likely understate the impacts of the California Program on both new vehicle prices and vehicle fleet emissions.

Changes in new vehicle prices and attributes due to the California Program will lead to decreases in the rates at which *used* vehicles are retired from service ("scrapped"). Our analysis of this

effect is based upon the results of a detailed statistical model linking vehicle scrappage rates for different vintages to new vehicle prices (among other factors). A decrease in scrappage of used vehicles leads to an increase in the average age of the vehicle fleet and thus to increased emissions, since older vehicles have higher emission rates than newer vehicles. The modeling also takes into account the effect of improvements in fuel economy on VMT (an effect known as the “rebound effect”) that leads to increases in emissions due to the greater number of miles traveled. The emissions estimates also include effects on emissions of changes in gasoline consumption associated with the extraction, processing, and transport of gasoline (referred to as “upstream” emissions).

Figure A-1 shows the results of our analyses of the effect of the California Program relative to the Federal Program on emissions of ozone precursors—the sum of volatile organic compounds (“VOC”) and nitrogen oxides (“NO_x”)—for the State of California from 2009 to 2023. These results were developed using the U.S. EPA’s MOBILE6.2 emission factor model. As Figure A-1 shows, our analysis indicates that the California Program will result in higher VOC+NO_x emissions in California than would occur under the Federal Program. We performed the same analysis using CARB’s EMFAC2007 emission inventory model, and generated similar results. Results for the South Coast Air Basin also show the same effect, modeled with either MOBILE6.2 or EMFAC2007. In addition to VOC+NO_x, we analyzed emissions of several other criteria air pollutants and air toxics. In general, we found that these emissions would be higher under the California Program, modeled with either MOBILE6.2 or EMFAC2007. The only exception is emissions of sulfur oxides, which decrease as a result of lower gasoline consumption under the California Program.

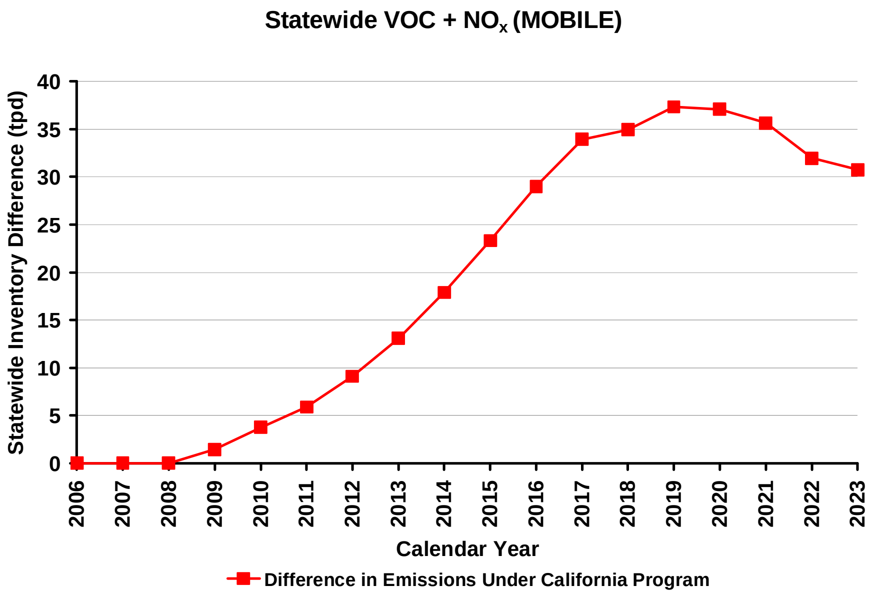

Figure A-1. Change in emissions of VOC + NO_x under the combined California Program, relative to emissions under the Federal Program.

These results reflect the higher costs associated with compliance with the California Program relative to the costs required to comply with the Federal Program, which lead to higher new vehicle prices, reduced new vehicle sales, and increased retention of used vehicles. The results also reflect the improvements in fuel economy due to the California Program that result in increased VMT and thus increased emissions.

In summary, our results indicate that the California Program, in the aggregate, is less protective of public health than the Federal Program with respect to emissions of ozone precursors and several other criteria pollutants.

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I. Introduction

This study evaluates the emissions impacts of the California regulations, including California's exhaust and evaporative emission standards, the ZEV Standards and the GHG Standards, (together, the "California Program") on emissions from new light-duty vehicles in California over the period from 2009 to 2023, relative to those that would occur in California under federal regulations on emissions from new light-duty vehicles (the "Federal Program"). The ZEV Standards and the GHG Standards are the two primary differences between the California Program and the Federal Program. To evaluate the ZEV and GHG Standards, we rely on documentation developed by California Air Resources Board ("CARB") staff describing the specific requirements and implementation processes of the Standards. The 2009 model-year was selected as the starting point for our analysis because that will be the first model-year affected by the GHG Standards as well as, according to CARB staff, the model-year by which, for the most part, manufacturers will have exhausted previously banked credits used for compliance with the ZEV Standards. The 2023 model-year was selected as the ending point for our analysis because 2023 is the year by which the South Coast Air Basin and all other areas of California must be in compliance with National Ambient Air Quality Standard for ozone.

A. Background

Emissions from motor vehicles were first associated with air pollution in the early 1950s when Professor A.J. Haagen-Smit determined that ozone is formed in the atmosphere by emitted volatile organic compounds ("VOC") and nitrogen oxides ("NO_x") reacting with one another in the presence of sunlight. This discovery precipitated the first motor vehicle emission controls aimed at reducing emissions of ozone precursors, which were put in place in the early 1960s, first by the State of California, and shortly thereafter by the federal government. Motor vehicles have also been identified as sources of carbon monoxide ("CO") and particulate matter ("PM"), as well as several air toxic emissions.

Concerns about "patchwork" state and local regulation of emissions from new motor vehicles led to the inclusion of Section 209 in the Clean Air Act of 1970. Section 209 prevents states other than California from adopting emission standards for new motor vehicles that differ from federal standards, and allows California to do so only if a waiver is granted by the U.S. Environmental

Protection Agency ("U.S. EPA"). Over the past forty years, CARB has, under the provisions of Section 209, established its own control program for emissions from new motor vehicles. One of the necessary conditions for the granting of a waiver established in Section 209 is that the California standards be "… in the aggregate at least as protective of public health as applicable Federal standards."

While the federal and California vehicle control programs have differed in a number of ways in the past, many aspects, particularly those addressing on-road, heavy-duty, diesel engines have recently come into alignment. Moreover, the exhaust and evaporative emission standards under Lev II in the California Program are similar to those under Tier 2 in the Federal Program. Nonetheless, there are currently two major differences between the California and Federal Programs for light-duty vehicles (i.e., vehicles with gross vehicle weight ratings of 8,500 pounds or less):

1. California's Zero Emission Vehicle ("ZEV") Standards ("ZEV Standards" or "ZEV Mandate"), which require that manufacturers produce and sell specified quanities of vehicles certified to CARB's Partial Zero Emission Vehicle ("PZEV"), Advanced Technology Partial Zero Emission Vehicle ("AT PZEV") and Zero Emission Vehicle ratings; and

2. California's Greenhouse Gas ("GHG") Exhaust Emission Standards ("GHG Standards") which establish limits on GHG emission rates for new vehicles in terms of carbon-dioxide-("CO_2")-equivalent emissions.

The costs imposed on manufacturers to comply with both the ZEV and GHG Standards are considerable, and, as documented in a number of studies, these high compliance costs result in decreased demand for new vehicles, increased retention of older vehicles, and increased emissions of criteria pollutants.[1] However, our previous studies have not analyzed the combined impacts of the entire California Program compared to the Federal Program.

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[1] That both the ZEV and GHG standards result in higher emissions of criteria pollutants has been extensively documented in previous studies submitted to CARB and attached to this study as Attachments A, B and C. Attachment A is a January, 2001 report by NERA and Sierra, *Impacts of Alternative ZEV Sales Mandates on California Motor Vehicle Emissions: a Comprehensive Study*. Attachment B is a March 23, 2003 report by NERA and Sierra, *Impacts of ZEV Sales Mandate on California Motor Vehicle Emissions: Implications of March 2003*

B. Objectives

This study utilizes a set of sophisticated models that allow for a quantitative comparison of the relative efficacy of the California and Federal Programs. The emission estimates presented in this study account for six categories of effects resulting from the implementation of the ZEV and GHG Standards.

1. *Effects on costs of new motor vehicles*. These effects include costs for manufacturing, new parts, and other expenses associated with compliance with the California Program, incremental to those required to comply with the Federal Program.

2. *Effects on the market for new vehicles*. Increases in production costs and modifications to vehicle characteristics necessary to comply with the California Program will affect new vehicle sales through price increases and changes in vehicle attributes.

3. *Effects on scrappage rates for existing vehicles*. Increases in new vehicle prices will result in changes in used vehicle markets that will decrease the rates at which used vehicles are retired from service ("scrapped"). Decreases in scrappage rates will lead to an increase in the average age of the vehicle fleet and to increased emissions, since older vehicles, on average, have higher emission rates than new vehicles.

4. *Fleet population effects*. The combination of lower new vehicle sales and increased retention of older vehicles will affect the overall composition of the motor vehicle fleet in California, relative to the fleet composition with the Federal Standards in place.

5. *Effects on vehicle miles traveled ("VMT")*. The GHG Standards and the ZEV Standards will both result in the implementation of various technologies that improve the fuel economy of new vehicles. Improved fuel economy will lower the cost of driving, leading vehicle owners to drive more miles each year. This effect, referred to as the "rebound effect," will tend to increase emissions, as emissions are directly related to VMT.

Proposal. Attachment C is a September, 2004 report by NERA and Sierra, *Environmental and Economic Impacts of the ARB Staff Proposal to Control Greenhouse Gas Emissions from Motor Vehicles*.

6. *Emissions effects*. Changes in the composition of the motor vehicle fleet, fleet VMT, and fuel consumption resulting from the California Program will result in changes in vehicle emissions in California, relative to those that would occur if the Federal Program were in effect.

C. Outline of Report

The remainder of this report is organized as follows: Chapter II provides an overview of the methodologies and data that are used in this study; Chapter III presents the results of the analyses; and Chapter IV provides brief conclusions. The appendices provide details on the methodologies and data, as well as supplemental results.

II. Methodologies and Data

This chapter provides summary information on the methodologies and data used to estimate the effects of the California Program. This chapter focuses only on the primary differences between the California Program and the Federal Program—namely the ZEV and GHG Standards; however, all modeling of the California and Federal Programs includes the full set of applicable light-duty vehicle emission standards. As noted, the appendices to this report provide details on the methodologies and data.

A. Overview of ZEV and GHG Standards

This section summarizes the requirements of the ZEV and GHG Standards, and the implications of these standards for the per-vehicle cost and fuel economy of new vehicles sold in California. In this study, we assume, based on recent statements by CARB staff,[2] that manufacturers will not, in general, incur significant compliance costs (beyond any already incurred) due to the ZEV Standards prior to the 2009 model-year. The GHG Standards do not cover vehicles before the 2009 model-year. Therefore, for the purposes of this study, we have modeled both the ZEV and GHG Standards as taking effect with the 2009 model-year.

The requirements of both the ZEV Mandate and the GHG standards vary depending on the number of vehicles a manufacturer sells annually in California. Although the requirements are complicated, in general, large volume manufacturers are defined as those that sell more than 60,000 vehicles per year in California, intermediate volume manufacturers are defined as those that sell between 3,001 and 60,000 vehicles per year and small volume manufacturers are defined as those that sell 3,000 vehicles per year or less. The provisions of the ZEV and GHG Standards that will lead to substantial compliance costs generally apply only to large volume manufacturers. However, those manufacturers account for the vast majority of vehicle sales in California. Based on 2003 California vehicle sales data from R.L. Polk, and anticipated growth in vehicle sales between then and the 2009 model-year, we have used the manufacturer designations shown in Table 1 to determine compliance obligations. Note that small volume manufacturers have no obligations under the ZEV or GHG Standards.

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[2] California Air Resources Board, 2007, “Status Report on the California Air Resources Board’s Zero Emission Vehicle Program.”

Table 1. Categorization of large and intermediate volume manufacturers included in this analysis.

Manufacturer	Category
BMW	Large Volume
Daimler-Chrysler	Large Volume
Ford	Large Volume
General Motors	Large Volume
Honda	Large Volume
Hyundai	Large Volume
Mitsubishi	Intermediate Volume
Nissan	Large Volume
Subaru	Intermediate Volume
Toyota	Large Volume
Volkswagen*	Large Volume

* Note that Volkswagen includes Porsche vehicles.

1. ZEV Standards

The ZEV Standards require that manufacturers "produce, deliver for sale, and place in service" a sufficient number of ZEV-credit-generating vehicles to meet the ZEV obligation specified by the ZEV Mandate for every year after the ZEV Mandate takes effect. The ZEV Mandate defines three categories of vehicles capable of generating ZEV credits:

1. Partial Zero Emission Vehicles ("PZEVs"), which include conventional vehicles that meet very stringent exhaust and evaporative emission requirements and warranty requirements;

2. Advanced Technology PZEVs ("ATPZEVs"), which consist of various types of hybrid electric vehicles;[3] and

3. Zero Emissions Vehicles ("ZEVs"), which include battery electric and hydrogen fuel cell vehicles.

Credits generated by PZEVs, AT PZEVs, and ZEVs are referred to as "Bronze," "Silver," and "Gold" credits, respectively. Table 2 provides some examples of the levels of ZEV credits and credit designations associated with specific types of vehicles over the period from 2009 to 2023.

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[3] It should be noted that other types of vehicle technologies such has hydrogen fueled spark ignition and compressed natural gas could be certified as AT PZEVs. However, based on confidential information we have received from vehicle manufacturers, we do not believe that any manufacturer plans to market such vehicles in significant quantities.

Table 2. Categories of ZEV-credit-generating vehicles, and range of credit values in the years 2009 - 2030.

Technology	Category	Credit Range (2009 - 2030)
PZEV	Bronze	0.2
Class A Hybrid Electric Vehicle (AHEV)	Silver	0
Class B Hybrid Electric Vehicle (BHEV)	Silver	0
Class C Hybrid Electric Vehicle (CHEV)	Silver	0 - 0.4
Class D Hybrid Electric Vehicle (DHEV)	Silver	0.6 - 0.45
Class E Hybrid Electric Vehicle (EHEV)	Silver	0.7 - 0.55
Plug-in Hybrid Electric Vehicle (PHEV) 10	Silver	1.88 - 2.03
Plug-in Hybrid Electric Vehicle (PHEV) 20	Silver	2.05 - 2.20
Plug-in Hybrid Electric Vehicle (PHEV) 40	Silver	2.34 - 2.49
Neighborhood Electric Vehicle (NEV)	Gold	0.15
TYPE 0 Electric Vehicle	Gold	1.0
Type I (City Electric Vehcile, "CEV")	Gold	2.0
Type II (Full Performance Battery Electric Vehicle, "FPBEV")	Gold	3.0
Type III (Fuel Cell Electric Vehicle, "FCEV")	Gold	3.0 - 4.0

Source: Calculated from CARB documentation of ZEV Standards.

The ZEV Mandate specifies two ways in which manufacturers may determine their ZEV credit obligation. The ZEV obligation is the minimum number of ZEV credits that a manufacturer is required to generate in any given year, and is expressed as a percentage of the manufacturer’s total sales volume of covered vehicles, which may either be current year sales (current year method) or the average of sales in fixed blocks of three earlier years (prior year method). The covered vehicle sales volume always includes 100% of the sales of Passenger Cars (“PCs”) and Class 1 Light Duty Trucks (“LDT1s”), while the coverage of Class 2 Light Duty Trucks (“LDT2s”) increases nearly linearly from 51% in 2009 to 100% in 2012 and beyond.

In calculating their ZEV obligations for each year, large volume manufacturers may either use the “Primary Requirements” (or “Primary Compliance Path”) or the “Alternative Requirements” (or “Alternative Compliance Path”). The Alternative Compliance Path sunsets with the 2017 model-year, and thereafter the Primary Requirements apply to all large volume manufacturers. Both compliance options set the same fixed percentage ZEV obligation in each year, and specify a minimum portion of the required ZEV credits that must be generated by pure ZEVs, and a maximum portion that may be generated by PZEVs. The difference between the sum of the ZEV and PZEV credits and the total ZEV requirement may be made up by credits generated by AT PZEVs. There are three major differences between the Primary Requirements and the Alternative Requirements:

1. The minimum ZEV requirement is a fixed percentage of the total covered sales volume under the Primary Requirements. For example, under the Primary Compliance Path, if a manufacturer's average yearly sales of covered vehicles from 2006-2008 is 200,000 (roughly ten percent of yearly industry-wide sales of covered vehicles in California), then that manufacturer would need to generate 6,000 Gold ZEV credits (three percent of its covered sales) ***in each year*** from 2012-2014 (using the prior year method to determine obligation), which equates to 2,000 pure ZEVs per year. However, under the Alternative Requirements, a target number of total Gold ZEV credits for the industry is specified for each three-year period, and each manufacturer's Gold ZEV credit obligation is calculated as the ratio of the manufacturer's total ZEV obligation in that period to the sum of the ZEV obligations for all manufacturers during that period, multiplied by the target number of total Gold ZEV credits for the industry for that period. For example, under the Alternative Compliance Path, if a manufacturer's sales of covered vehicles from 2006-2008 account for ten percent of industry-wide sales of covered vehicles from 2006-2008, then that manufacturer would need to generate 7,500 Gold ZEV credits (ten percent of the Gold ZEV credit target for the industry) ***during the entire period*** from 2012-2014 (using the prior year method to determine obligation), which equates to 2,500 pure ZEVs over the period, or about 833 pure ZEVs per year. In general, the Alternative Requirements require fewer pure ZEV sales than the Primary Requirements. Under the Alternative Compliance Path, manufacturers can make up the reduced Gold ZEV credit obligation with credits generated by AT PZEVs to meet their total ZEV obligation.

2. Under the Primary Requirements, manufacturers are permitted to satisfy their Gold credit requirements using any of the Gold category vehicles listed in Table 2. Under the alternative requirements, Gold credits must be obtained from Fuel Cell Electric Vehicles ("FCEVs").

3. The Primary Requirements permit the use of either the prior year or current year method for determining ZEV obligations. The Alternative Requirements require use of the prior year method.

Based on the high costs associated with generating Gold ZEV credits with either battery electric or fuel cell vehicles, and based on discussions with vehicle manufacturers regarding their ZEV compliance plans, we have assumed, for the purposes of this study, that all large volume manufacturers would choose to meet the Alternative Requirements until they sunset with the 2017 model-year (see Appendix A for a full analysis of compliance plan options and choices). The requirements for large volume manufacturers using the Alternative Compliance Path are summarized in Table 3. Intermediate volume manufacturers may meet their entire ZEV obligation with credits generated by PZEVs, and small manufacturers are not covered by the ZEV mandate.

Table 3. Requirements for large volume manufacturers under the Alternative Compliance Path.

Model Years	Minimum ZEV Requirement (as share of prior year production volume)	Percentage LDT2 Included in ZEV Obligation (Range)	Target Number of FCEV Credits	Maximum PZEV Credits (as share of prior year production volume)
2009 - 2011	11%	51% - 85%	10,000	6.00%
2012 - 2014	12%	100%	75,000	6.00%
2015 - 2017	14%	100%	150,000	6.00%
2018 -	16%	100%	Sunsets	6.00%

Source: CARB documentation of ZEV Standards.[4]

The Primary Requirements also set a fixed percentage ZEV obligation in each year. However, under the Primary Requirements, the Gold ZEV credit obligation is more stringent than under the Alternative Requirements. Table 4 summarizes the Primary Requirements.

2. GHG Standards

The GHG Standards establish a set of CO_2 emission rate standards for large volume manufacturers that apply to 2009 and subsequent model-year vehicles, with a "near-term" standard phased in from 2009 to 2012 and a "mid-term" standard phased in from 2013 to 2016.

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[4] Note that the Pure ZEV credit requirement is given as a total number of credits required, rather than as a share of prior year production volume. Each manufacturer's share of the total number of credits is calculated for each three-year block in accordance with the methodology described in CARB documentation of the ZEV Standards.

Table 5 shows the CO_2-equivalent standards for the two categories of vehicles to which they apply: PC/LDT1 and LDT2+. Note that "LDT2+" includes LDT2s and certain medium duty vehicles ("MDVs").

Table 4. Requirements for large volume manufacturers under Primary Compliance Path.

Model Years	Minimum ZEV Requirement (as share of prior or same year production volume)	Percentage LDT2 Included in ZEV Obligation (Range)	Pure ZEV Requirement (as share of prior or same year production volume)	Maximum PZEV Credits (as share of prior year production volume)
2009 - 2011	11%	51% - 85%	2.50%	6.00%
2012 - 2014	12%	100%	3.00%	6.00%
2015 - 2017	14%	100%	4.00%	6.00%
2018 -	16%	100%	5.00%	6.00%

Source: CARB documentation of ZEV Standards.

This study estimates the effects of the GHG Standards based upon a detailed analysis of manufacturer technology choices and their costs and effectiveness that was submitted to CARB in 2004, and which formed the basis of our previous analysis of the emissions impacts associated with the GHG standards (see Attachment C for details). Our estimates of the per-vehicle costs of the GHG Standards were developed based on the assumption that each covered manufacturer minimizes its costs (for all of its covered vehicles) of meeting the final 2016 mid-term standard. The costs for intervening years are based upon assessments of the mix of the final compliance technologies that would be employed by each manufacturer for different vehicle types. We developed a separate trajectory of per-vehicle costs and fuel economy changes for each of four vehicle types: (1) passenger cars; (2) minivans; (3) pick-up trucks; and (4) sport-utility vehicles ("SUVs").

Table 5. GHG Standards.

Tier	Year	CO2 - Equivalent Emission Standard by Vehicle Category (g/mi)	
		PC/LDT1	LDT2+
Near-term	2009	323	439
	2010	301	420
	2011	267	390
Mid-term	2012	233	361
	2013	227	355
	2014	222	350
	2015	213	341
	2016	205	332

Source: CARB documentation of GHG Standards.

B. Overview of Methodology

The overall methodology developed for this study consists of a set of inter-related models designed to evaluate the effects of the California Program on the California vehicle fleet and on California fleet emissions. Figure 1 shows the primary components of the modeling framework. These components include: (1) the Engineering Cost Model, which develops expected compliance plans for individual manufacturers based on information on the available technologies and strategies for compliance with the ZEV and GHG Standards, including data on the costs and emissions reductions, as well as the ZEV credit value, of each technology; (2) the New Vehicle Market Model ("NVMM"), which estimates the impacts of the regulations on the prices and quantities of various new motor vehicle models, taking as inputs the costs and vehicle characteristic (e.g., fuel economy) effects, as well as the ZEV credit value, of the various technologies in manufacturers' compliance plans; (3) the Scrappage Model, which estimates the effects of changes in the prices of new vehicles on the rate at which used vehicles are scrapped; (4) the Fleet Population Model, which estimates the effects of changes in new vehicle sales and the scrappage rates of existing vehicles on overall vehicle fleet populations over time; (5) the VMT Model, which assesses effects on vehicle miles traveled; and (6) the Emissions Model which assesses effects on pollutant emissions. The following sections provide summaries of the

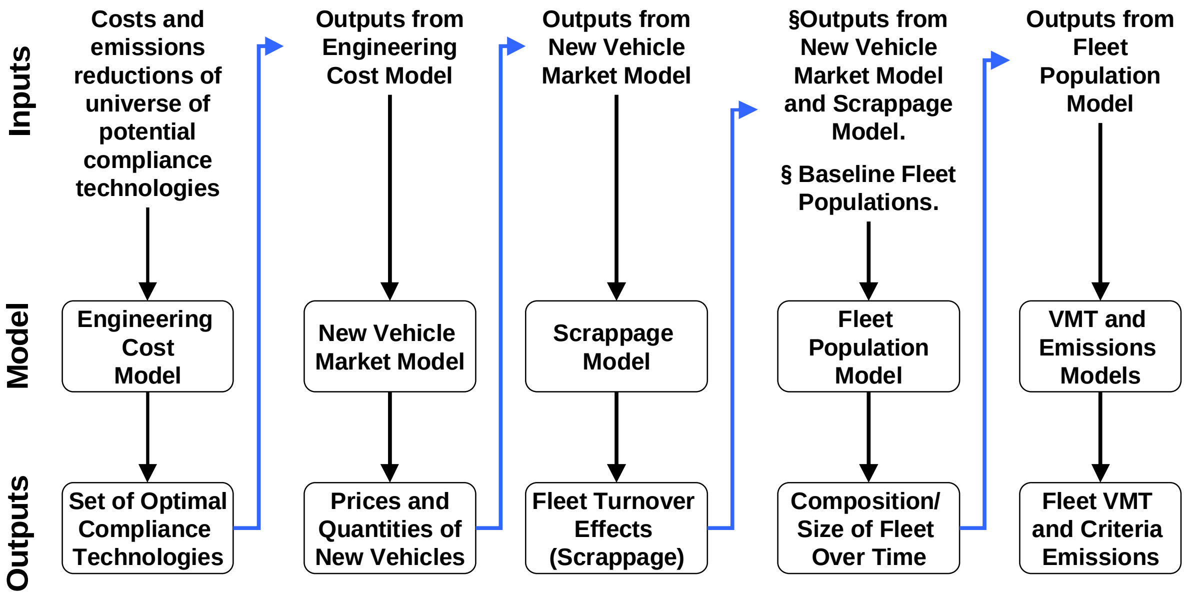

Figure 1. Diagram of modeling framework and process.

six models, including various subcomponents and related data.

C. Compliance Plans and Cost Estimates[5]

The starting point for this study was the development of estimates of vehicle costs associated with the ZEV and GHG Standards. As discussed below (and in more detail in Appendix A), these cost estimates are incremental to the costs associated with the production of a conventional gasoline-fueled Super-Ultra Low Emission Vehicle ("SULEV"); the incremental costs of SULEVs relative to federal Tier 2 vehicles were ignored. To the extent that SULEVs cost more than equivalent Tier 2 vehicles, this would tend to understate vehicle costs under the California Program relative to the Federal Program. Estimates of costs for compliance with the ZEV Mandate were developed for the three categories of vehicles capable of generating ZEV credits: (1) Partial Zero Emission Vehicles (PZEVs); (2) Advanced Technology Partial Zero Emission Vehicles (ATPZEVs), and; (3) Zero Emission Vehicles. Within these categories, separate cost estimates were developed for vehicles employing different technologies and for distinct vehicle classes (PC+LDT1 and LDT2). Compliance costs associated with the GHG Standards used in this analysis were developed previously by Sierra and supplied to CARB at the time the GHG regulations were adopted in Sierra's 2004 report.[6]

In estimating the costs of vehicles required for the ZEV mandate, a number of different sources of information were used, including the recently published "Report of the ARB Independent Expert Panel 2007," confidential cost information supplied by individual auto manufacturers, and cost estimates provided by The Martec Group and Harbour Consulting. As described below, we elected to make conservative assumptions in preparing these cost estimates that likely underestimate the true costs.

1. PZEV Costs

Incremental cost estimates for PZEV technology of $350 and $500 per vehicle were used for PC+LDT1 and LDT2 vehicles, respectively. The PC+LDT1 value reflects the lower range of the

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[5] All costs referred to in this section and in Appendix A are in year 2004 dollars. The NVMM escalates these to year 2005 dollars using the Consumer Price Index in order to be consistent with other data used in the modeling.

[6] Austin, T.C., et al., 2004, "Review of the August 2004 Proposed CARB Regulations to Control Greenhouse Gas Emissions from Motor Vehicles: Cost Effectiveness for the Vehicle Owner or Operator", Sierra Research Report No. SR2004-09-04, September, 2004.

cost data supplied by vehicle manufacturers, while the LDT2 value reflects the middle of that range. The use of the higher value for LDT2 reflects the higher expenses of achieving the zero-evaporative emission standard for PZEVs under the ZEV Mandate on vehicles with larger fuel tanks and the higher expenses of achieving the exhaust emission standard for PZEVs under the ZEV Mandate on larger vehicles with V8 engines.

2. ATPZEV Costs

Incremental cost estimates for Type C, D and E hybrid electric vehicles were $1,800, $2,200 and $5,500, respectively. These are based on the methodology documented in Sierra's 2004 report, with the estimates for Type D and E vehicles reflecting additional costs associated with high voltage electrical systems, nickel-metal hydride batteries, electric motors and control systems. The cost of plug-in hybrid electric vehicles (PHEVs) with 10, 20 and 40 mile electric range in the PC+LDT1 category was estimated using component cost estimates provided by The Martec Group (the consulting firm relied on by CARB to provide cost information in support of the GHG rulemaking), and data from the report of the Independent Expert Panel. Incremental cost estimates ranged from about $10,500 for a 10 mile all electric range to about $15,000 for a 40 mile all electric range. Costs for LDT2 vehicles were again estimated by scaling the PC+LDT1 values by the relative sales-weighed average weights of 2003 model-year vehicles in these classes. Estimates for Type C, D and E hybrid electric vehicles are based on the methodology documented in Sierra's 2004 report, but have been updated to reflect the latest available cost data. The cost of plug-in hybrid electric vehicles (PHEVs) in the PC+LDT1 category has been estimated using component cost estimates provided by The Martec Group (the consulting firm relied on by CARB to provide cost information in support of the rulemaking for the GHG Standards), and data from the report of the Independent Expert Panel. Costs for LDT2 vehicles were estimated by scaling the PC+LDT1 values by the relative sales-weighed average weights of 2003 model-year vehicles in these classes.

3. Pure ZEV Costs

We estimate a cost for Neighborhood Electric Vehicles ("NEVs") of $8,000, based on the nominal $8,000 price of NEVs produced by Global Electric Motors. Because of their limited range and performance, NEVs are unlikely to be general replacements for conventional vehicles, although they would displace some conventional vehicle travel. Therefore, NEV purchase was viewed as a cost in addition to owning a conventional vehicle. Incremental costs for City Electric Vehicles were assumed to be equal to $13,122 which is the cost of the vehicle battery. Utility EV costs were assumed to be 2/3 that of a city electric vehicle given the respective range requirements of 50 and 75 miles.

The cost of full performance battery electric vehicles (FPBEV) was also estimated using data from Martec. In the case of pure electric vehicles, the cost of electric motors and power electronics is sometimes assumed to be offset by the cost savings associated with elimination of the internal combustion engine and transmission. However, using cost information provided by Martec and Harbour Consulting, the net cost of the non-battery changes is about $2,500 for a full-function EV with a 100 mile range. Using the simple assumption that only the battery cost need be accounted for, the incremental cost increase associated with a full-function EV is $26,400. If the range is reduced to 75 miles, the cost increase drops to about $19,900. For this study, we replaced the more realistic Martec battery cost estimates with the Expert Panel's average cost estimates for lithium-ion batteries, and then added the net cost of the non-battery changes described above. We used the lower volume cost estimate through the 2012 model-year and then linearly transitioned to the high volume cost estimate for 2015 and later model-years. This resulted in a near term incremental cost estimate of about $23,000 for a FPBEV and a longer term incremental cost of about $17,000.

The incremental cost of fuel cell electric vehicles (FCEVs) was estimated using the average of the Expert Panel's best case current and 2015 estimates for fuel cell system costs in high volume production, and an assumed stack rating of 100 kW. The current best-case costs were used through the 2012 model-year, and then linearly transitioned to the 2015 value in that year and beyond. Thus, the incremental costs assumed for FCEVs were about $60,000 in the short term and about $11,000 in the longer term.

4. Selection of Compliance Plans

Using the cost estimates described above, we estimated the costs per ZEV credit for a wide variety of vehicles (as described in detail in Appendix A). Based on this, we determined that the most cost-effective approach for compliance with the ZEV Standards would be for large volume manufacturers to pursue the Alternative Compliance Pathway through the 2017 model-year, and then to continue production of FCEVs to meet their "Gold" ZEV credit obligations thereafter.

We also determined that, under the conservative (e.g., low-cost) assumptions used in this study, manufacturers would not be required to deploy advanced (Type E) hybrid electric vehicles in order to comply with the GHG standards. As a result, we assumed that manufacturers would produce Type D HEVs that comply with the AT PZEV requirements in order to generate “Silver” ZEV credits. We also assumed that manufacturers would use PZEVs to generate “Bronze” ZEV credits to the extent allowed under the ZEV Standards.

We assume that manufacturers preferentially incorporate AT PZEV and PZEV technologies into PCs and LDT1s because the costs of doing so are lower than the costs of incorporating them into LDT2s. However, some manufacturers with a relatively high percentage of sales from LDT2s must develop some LDT2 PZEV and AT PZEV platforms in order to comply with the ZEV Standards. We model the penetration of PZEV and AT PZEV technologies into LDT2s to the extent necessary for manufacturers to achieve compliance.

As noted above, the Alternative Compliance Path requires Large Volume Manufacturers to generate ZEV credits by producing Fuel Electric Cell Vehicles (“FCEVs”) based on hydrogen fuel cells. FCEVs face major challenges associated with the lack of a hydrogen refueling infrastructure in addition to the high costs associated with FCEV development and production. As stated above, we have relied upon highly optimistic (“best case”) assumptions regarding the costs of FCEVs. In addition, we have also made optimistic assumptions about the demand for FCEVs (see Appendix B).

D. New Vehicle Market Model

This section summarizes the major data and methodologies used to develop the New Vehicle Market Model (“NVMM”). A detailed description of the New Vehicle Market Model is provided in Appendix B.

1. Effects Modeled

The ZEV and GHG standards will affect the market for new vehicles in California in several ways. Our modeling framework includes the elements listed below.

§ Relevant additional costs incurred by manufacturers to modify motor vehicles to achieve the GHG emission reductions required for compliance with the GHG standards and/or relevant additional costs incurred to modify vehicles to qualify as PZEVs, AT PZEVs, or ZEVs as required by the ZEV standards.

- Benefits to consumers of improvements to vehicle fuel economy.[7]

- Shifts in the mix of new motor vehicles due to these additional costs, which differ by type of vehicle, model, and manufacturer.

- Substitution towards vehicles produced by Intermediate Volume Manufacturers and Small Volume Manufacturers. This is relevant for both the GHG Standards, which do not require Intermediate Volume Manufacturers to meet the 2012 standards until 2016, and for the ZEV Standards, which allow Intermediate Volume Manufacturers to fulfill their ZEV requirements using PZEVs. (Neither regulation imposes requirements on Small Volume Manufacturers).

2. Nested Logit Model

The NVMM is a nested logit model. Appendix B provides details of the nested logit framework and the data used to develop the model. Economists and other analysts have used nested logit models to evaluate factors affecting the demand for motor vehicles and other goods.[8] Nested logit models have also have been used in court proceedings to evaluate the effects of mergers and other changes in market conditions (see, e.g., Werden, Froeb and Tardiff 1996), and in various settings to evaluate the potential market demand for new products and services (see, e.g., Tardiff 1998).

The “nests” in the nested logit model refer to the structure assumed for consumer choices in the new vehicle market. Our model assumes that consumers face decisions structured regarding the purchase of a new motor vehicle, as shown in Figure 2 (described in more detail in Appendix B). Consumers choose whether to purchase a new vehicle or not. Conditional on the choice to

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[7] The NVMM does not attempt to account for losses to consumers due to weight reductions that could result if manufacturers comply with the GHG Standards by intentionally reducing vehicle weight; such weight reductions would be viewed negatively by consumers, assuming other attributes are held constant, and therefore would be expected to increase the fleet impacts due to the GHG Standards.

[8] Dr. Daniel McFadden was awarded the 2000 Nobel Prize in Economics largely for his development of the logit model.

purchase a new vehicle, they select the type of vehicle from among three major vehicle types—cars, SUVs/minivans, and trucks. Conditional on the choice of a vehicle type, they select a specific vehicle category. Our model includes a total of 15 vehicle categories, including six passenger cars, six SUVs/minivans, and three trucks/vans (e.g., pick-ups and full vans). Finally, conditional on the choice of a vehicle class, consumers choose from the vehicle models that are available in that class.

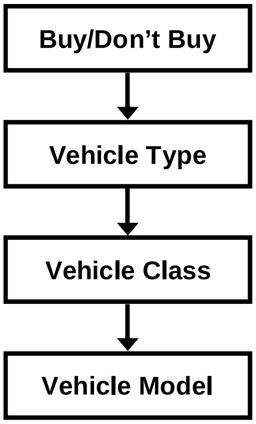

Figure 2. Hierarchy of NVMM nesting structure.

This structure provides for a rich pattern of own- and cross-price elasticities for different vehicle models. The empirical estimates provide information on more than 200 separate vehicle models in each year. The aggregate new vehicle price elasticity is assumed to be –1.0, a value consistent with the empirical literature.[9] New vehicle manufacturers are assumed to be profit-maximizing firms. The empirical formulation of the logit model used in this study is based upon new vehicle sales, price, and characteristics information for the years 2001 through 2005.

The NVMM estimates the effects of the ZEV and GHG standards on new vehicle prices and sales.[10] The model allows for consumer substitution among vehicles that are affected differentially by the regulations. Vehicles produced by manufacturers with lower sales volumes are subject to less stringent emissions standards under the GHG standards in the early years of the regulation and thus have lower cost increases and corresponding fuel economy changes during those years. Under the ZEV Standards, intermediate volume manufacturers may meet

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[9] c.f. Gruenspecht (2000) in Appendix B.

[10] All nine large volume manufacturers, as well as the intermediate volume manufacturers in Table 1, are modeled in the NVMM using the cost estimates and compliance plans described above.

their entire ZEV obligation with credits generated by PZEVs. The model allows for these differences to be reflected in changes in vehicle sales by model and manufacturer.

3. Pricing Decisions by Manufacturers

The California Program imposes several requirements on intermediate and large volume manufacturers that influence their profit-maximizing pricing strategies. For example, manufacturers must generate at least some number of ZEV credits each year, and some share of these credits must be generated using specific technologies (e.g. PZEV, AT PZEV, or ZEV-qualifying technology choices). Moreover, the number of credits required is dependent on vehicle sales in prior years. The NVMM accounts for these influences and their lagged structure in forecasting the effects of the ZEV and GHG standards.

E. Scrappage Model

The Scrappage Model estimates the effect of changes in the new vehicle market—including prices and quantities of different types of vehicles sold—on the rate at which used vehicles are retired from service (“scrapped”). It is a statistical model that estimates how scrappage rates respond to changes in the prices of new vehicles, as well as to changes in a variety of other variables.

Previous research has established that new vehicle prices affect used vehicle scrappage rates.[11] When the prices of new vehicles increase, the values of used vehicles also increase, and vehicle owners retain them for a longer period of time. Figure 3 illustrates how a change in new vehicle prices causes an increase in the demand for (and thus the value of) used vehicles. This increased demand results in a decrease in the scrappage rates of older vehicles.

The scrappage model is a detailed empirical model of the effect of changes in new vehicle prices on existing vehicle scrappage rates. The scrappage model is described in detail in Appendix C. Using a conceptual framework developed by previous researchers, we have developed an updated statistical model relating used vehicles’ scrappage rates to new vehicle prices. The model includes statistically estimated relationships between scrappage rates for vehicles of different model year vintages at each age during their lifetimes to new vehicle prices and other relevant factors.

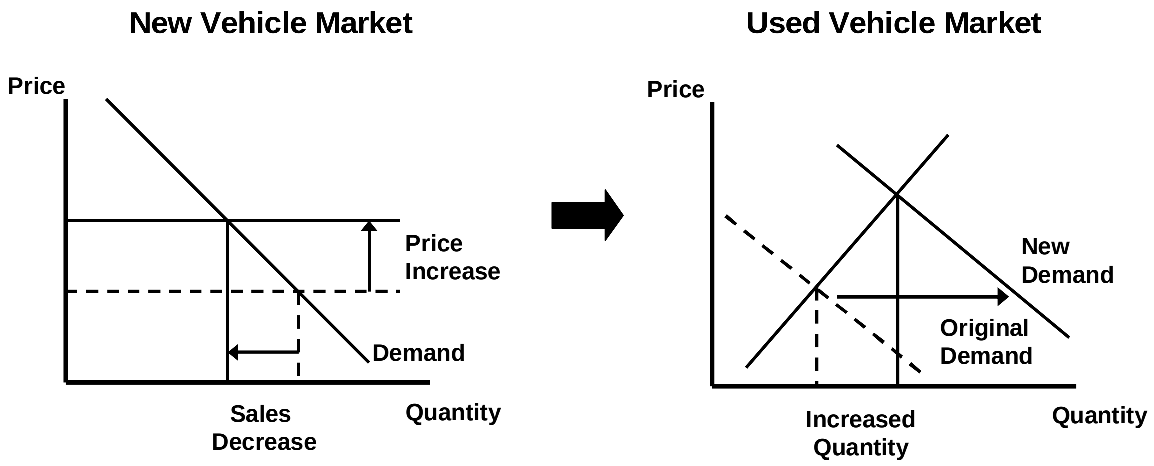

Figure 3. Effects of changes in new vehicle prices on prices of used vehicles.

F. Fleet Population Model

The Fleet Population Model combines the results of the NVMM and the Scrappage Model, and projects changes in the relevant fleet populations over time.

The empirical results from the Scrappage Model are used in combination with the new vehicle sales effects from the NVMM to assess the net effects of the California Program on the California vehicle fleet. We develop a detailed baseline forecast of the California vehicle fleet population based upon the vehicle populations in the CARB's EMFAC2007 emission inventory model.[12] Fleet population effects are measured relative to the baseline vehicle populations. In this study, both the EMFAC2007 emission modeling and MOBILE6.2 emission modeling use the same baseline populations and fleet effects.

As described above, the NVMM estimates the effects of the California on new vehicle sales, while the Scrappage Model estimates the effects on existing vehicle stocks. Applying the results of both of these models to the baselines in the Fleet Population Model allows us to simulate the effects of the regulations on the vehicle populations in California through the year 2023.

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[11] c.f. Gruenspecht in Appendix C.

[12] The EMFAC2007 model includes the LEV1 program, the LEV2 program, and the ZEV mandate. We utilize the populations by vehicle class in the EMFAC2007 model as our baseline (with emission rates appropriate for the federal Tier 2 program), and we estimate fleet effects relative to these populations.

G. Modeling of Effects on Vehicle Miles Traveled (“VMT”)

The results of the Fleet Population Model provide an important component for estimating the overall effects of the regulations on motor vehicle emissions. In addition to fleet effects, the emissions of the motor vehicle fleet also depend on VMT. We developed a model to explain overall VMT in order to provide estimates of changes in VMT due to the California Program (relative to baseline VMT).

Increasing the fuel economy of a vehicle (with all else equal) can lower the vehicle’s emission rates. However, it also lowers the cost per mile of driving, leading drivers to travel more miles. Thus, increasing fuel economy also raises VMT. Since total emissions depend on both emission rates (i.e., emissions per mile) and VMT, the effect of a decrease in emissions rates is partially offset by an increase in VMT. This offset is known as the “rebound effect.”

The VMT Model evaluates the effect on VMT of changes in the cost per mile of travel in California. (The VMT model is described in detail in Appendix D.) Based on a framework developed by researchers at the University of California, Irvine, we estimate relationships between cost-per-mile of travel, miles traveled, and other relevant factors. Using the results of this analysis, we develop estimates of the rebound effect for California, both in the short run and in the long run. We then use these estimates to determine the total change in VMT due to the California Program.[13]

H. Pollutant Emissions Models

We performed emission modeling with both EMFAC2007 emission rates and MOBILE6.2 emission rates. Baseline vehicle populations, baseline scrappage rates, and baseline vehicle miles traveled for both models used information from the EMFAC2007 model. Effects of fleet turnover and rebound VMT were identical in both emission modeling approaches. Emission rates by model year and vehicle class, however, were dependent on the different emission factors for each model.

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[13] Note that the rebound effect is relevant to both the ZEV Standards and the GHG Standards. The Type D Hybrid Electric Vehicles that manufacturers will produce to generate AT PZEV credits have higher fuel economy than conventional gasoline vehicles. Reducing CO_2 emissions from motor vehicles as called for in the GHG Standards results in improvements in fuel economy.

Below we describe how fleet turnover effects and rebound effects were incorporated into the two emissions modeling approaches. Appendix E provides further information about the EMFAC2007 emission rates and contains detailed results from the EMFAC2007 modeling, while Appendix F provides detailed information about the MOBILE6.2 modeling and detailed MOBILE6.2 results. Appendix G describes emissions effects associated with reduced gasoline consumption under the California Program.

1. Emissions Increases due to Fleet Population Effects

As noted earlier, the new vehicle price increases resulting from the ZEV and GHG standards will affect fleet turnover by reducing new vehicle sales and inducing higher rates of retention of older, higher-emitting vehicles. These effects lead to increases in criteria pollutant emissions, as older vehicles in the fleet often have emission rates that are many times higher than those of new vehicles. Our estimates assume that overall VMT is not affected by these shifts in the age of the vehicle fleet.

2. Emissions Increases Due to Rebound Effect

The rebound effect only affects vehicles for which fuel economy under the California program is improved relative to fuel economy under the Federal Program. The rebound effect is accounted for after the effects of fleet turnover are incorporated into the modeling. The rebound effect is modeled by employing the VMT model described in Appendix D to generate the increased VMT (above baseline VMT) for vehicles with improved fuel economy.

III. Study Results

This chapter summarizes the results of our analyses of the effects of the California Program. The results are grouped into three categories:

1. Motor vehicle market effects;
2. Effects on vehicles miles of travel; and
3. Emissions effects.

The graphs presented below reflect changes in various quantities under the California Program relative to what these quantities would have been under the Federal Program. Accordingly, positive values indicate that the quantity under the California Program is greater than under the Federal Program, whereas negative quantities indicate the converse. Detailed emission results are provided in Appendix E and Appendix F.

A. Motor Vehicle Fleet Effects

In this section, we present results of our analysis of motor vehicle fleet effects under the California Program. Figure 4 provides an illustrative snapshot of the changes in age distribution

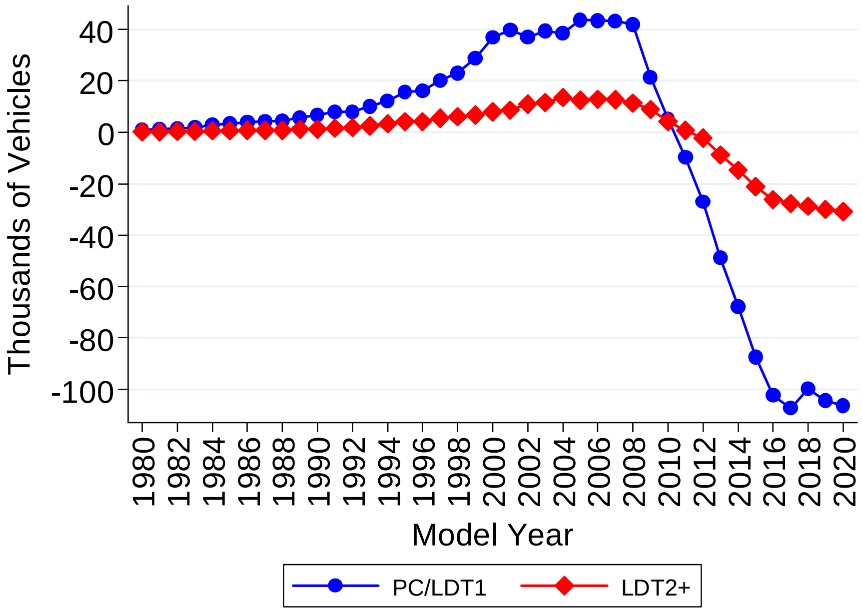

Figure 4. Change in statewide 2020 vehicle population estimates as a result of the combined California Program, relative to populations under the Federal Program.

of the vehicle fleet under the California Program relative to baseline populations consistent with the Federal Program for both the PC+LDT1 vehicle category and the LDT2+ vehicle category. The California Program has the effect of changing the age distributions of the fleets in both vehicle categories. In 2020, sales of new vehicles in the regulated fleet are significantly lower than baseline sales in California as a result of the California Program. In contrast, the number of vehicles in the fleet that were purchased before the effective date of the regulations (i.e., pre-2009 vintages) is significantly higher than the baseline number in 2020. In the year 2020, the number of vehicles of vintages 2008 and older is higher than the baseline number because consumers opt to retain their existing vehicles longer, rather than replacing them with more expensive newer vehicles.

Results are similar for the South Coast Air basin, as shown in Figure 5. As a result of the California Program, the population of motor vehicles of older vintages (those produced before 2009) in the South Coast vehicle fleet in the year 2020 is larger, and the population of motor vehicles of more recent vintages (those produced after 2009) in the fleet in 2020 is smaller than it would be under the Federal Program. In 2020, new vehicle sales of PC/LDT1's and LDT2+'s combined are about 40,000 fewer as a result of the California Program. In contrast, the number of vehicles in the fleet produced prior to the effective date of the ZEV and GHG Regulations

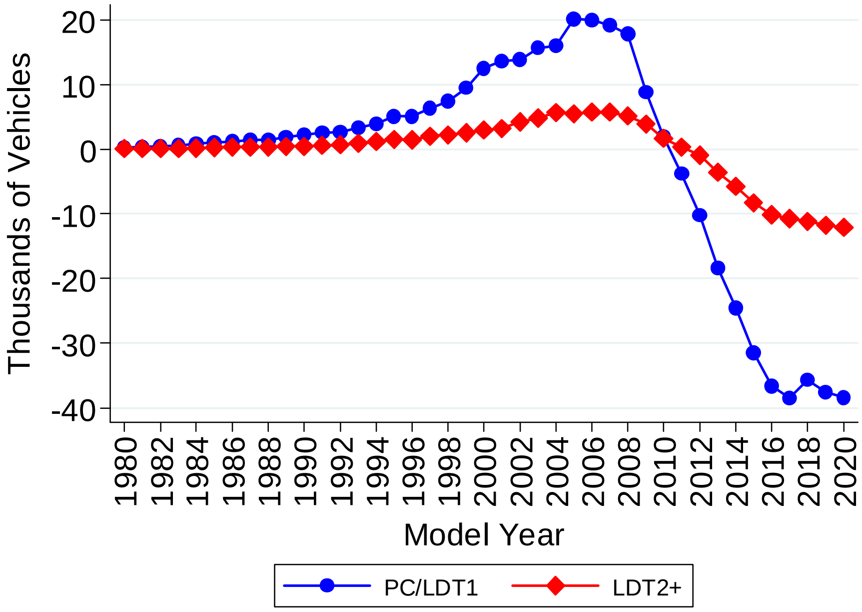

Figure 5. Impacts of the combined California Program on South Coast 2020 Vehicle Population, relative to populations under the Federal Program.

(i.e., pre-2009 model year vehicles) is more than 250,000 greater in 2020 than it otherwise would be under the Federal Program.

B. VMT Effects

Figure 6 shows the change in vehicle miles traveled statewide under the California Program, relative to baseline VMT under the Federal Program. By 2023, motorists are projected to drive approximately 14 million additional miles per day due to the California Program. This increase in VMT partially offsets any emission decreases due to improved fuel economy.

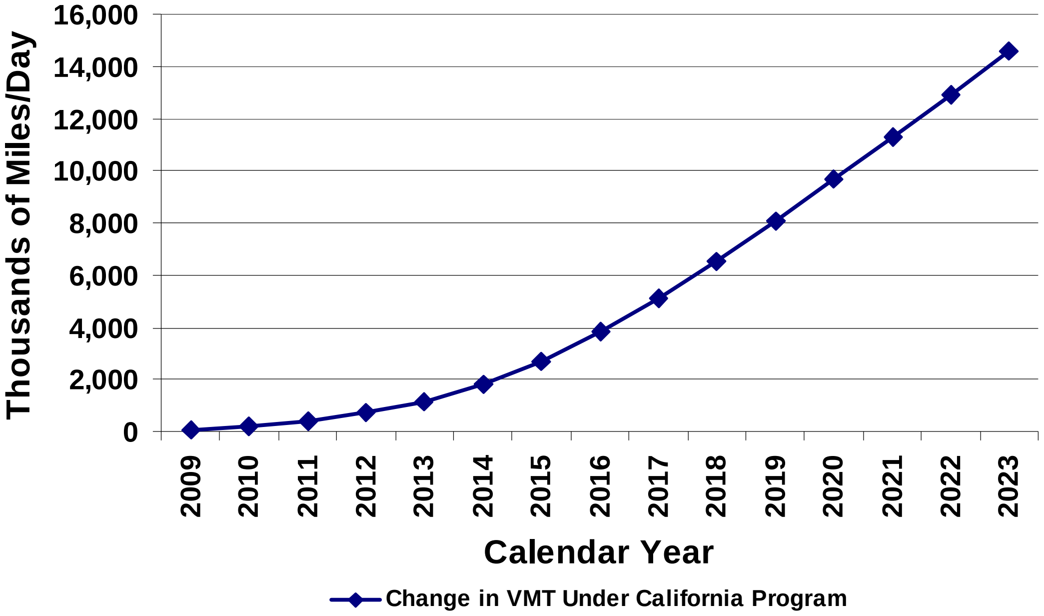

Figure 6. Change in vehicle miles traveled under combined California Program relative to VMT under Federal Program.

C. Fuel Consumption and Upstream Emissions Effects

Due to the fuel economy improvements resulting from the California Program, consumption of gasoline decreases (although this decrease is partly offset by the increase in VMT). The net decrease in gasoline consumption leads to a small decrease in emissions associated with the refining and transport of gasoline (upstream emissions). Figure 7 shows the change in statewide emissions of NMOG + NO_x due to the upstream emissions effect.

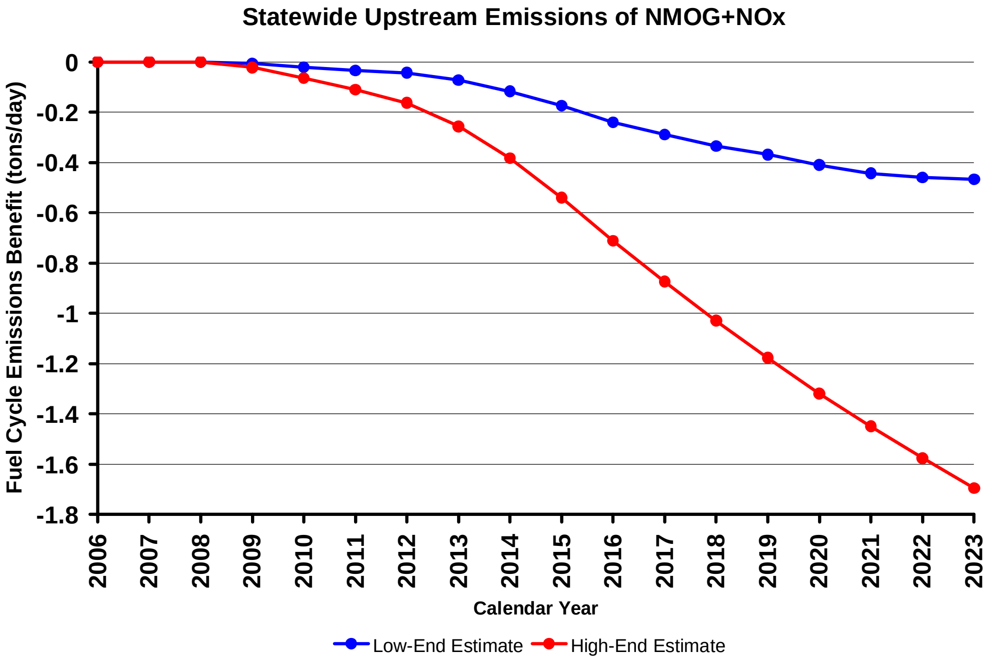

Figure 7. Change in statewide upstream emissions of NMOG + NOx due to the upstream emissions effect under combined California Program (relative to upstream emissions under Federal Program).

D. Overall Pollutant Emissions Effects

Below we provide overall assessments of the effects of the California Program on emissions of ozone precursors (VOC+NO_x) in the State of California and the South Coast Air Basin. Additional results for VOC+NOx, VOC, NOx, CO, Toxics, Exhaust $PM_{2.5}$, and SO_x, for both California and the South Coast Air Basin, are shown in Appendix E and Appendix F. As noted, our assessments are based on two different emission models. The first sub-section presents results generated using CARB's EMFAC2007 emission inventory model, and the second sub-section presents analogous results generated using the U.S. EPA's MOBILE 6.2 emission factor model.

a. EMFAC2007 Model Results

The differences in emissions under the California Program relative to the Federal Program based on summer season inventories from EMFAC2007 for calendar years 2006 through 2023—after accounting for the fleet turnover, rebound, and upstream emissions effects—for the state and South Coast Air Basin are shown in Figure 8 and Figure 9, respectively. As shown, the EMFAC 2007 results indicate that emissions of ozone precursors, both on a statewide basis and in the

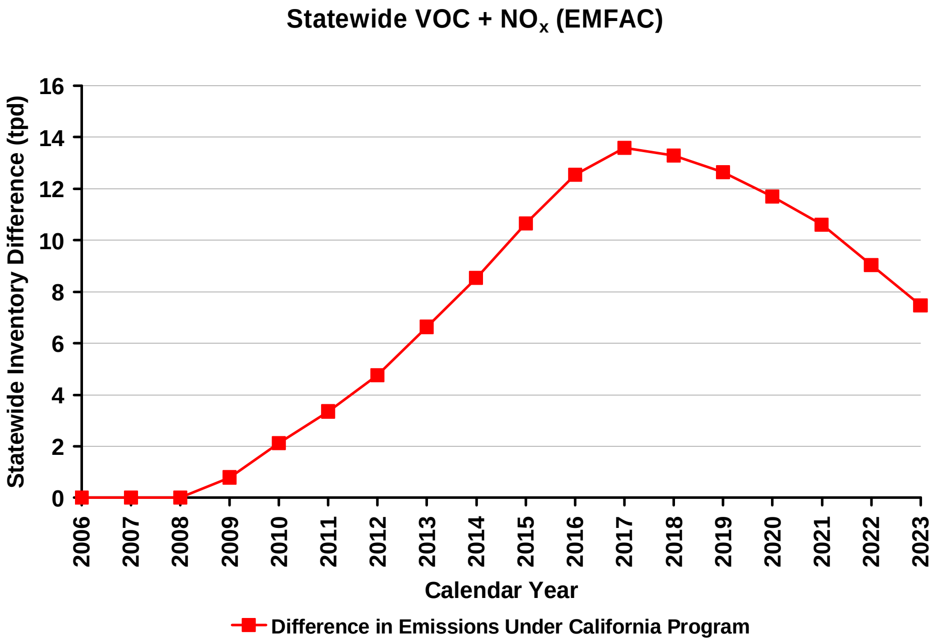

Figure 8. Change in statewide emissions of VOC+NO$_x$ (EMFAC2007 modeling) under combined California Program, relative to emissions under Federal Program.

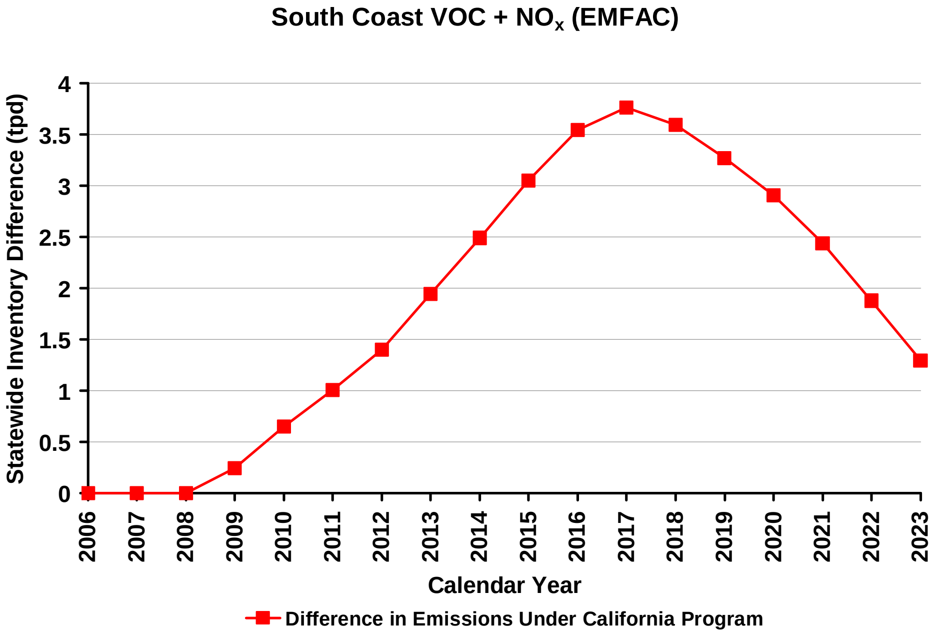

Figure 9. Change in South Coast emissions of VOC+NO$_x$ (EMFAC2007 modeling) under combined California Program, relative to emissions under Federal Program.

South Coast Air Basin (SCAB), are higher as a result of the California Program relative to the Federal Program in every year from 2009 through 2023. Similar results are observed for CO and $PM_{2.5}$ emissions. Emissions for toxic air contaminants are generally higher under the California Program through about 2018 and then decrease to essentially the same level as the federal program, or, in some cases, to a somewhat lower than the federal program (see Appendix E for additional results of EMFAC modeling). It must be noted, however, that the emission estimates for the Federal Program do not reflect U.S. EPA's recently adopted rules that will further reduce emissions of air toxics from motor vehicles. Emissions of SO_x are lower under the California Program than under the Federal Program due to reductions in gasoline consumption that result from the GHG standards.

b. MOBILE 6.2 Model Results

The results of the analysis performed using the MOBILE6.2 model are qualitatively similar to the results of the EMFAC2007 modeling, but the emission differences between the California and Federal Programs are larger in magnitude (as are the emission inventories themselves). As shown in Figure 10 and Figure 11, the California Program leads to an increase in emissions of ozone precursors ($VOC+NO_x$) over the entire period from 2009 through 2023, both on a

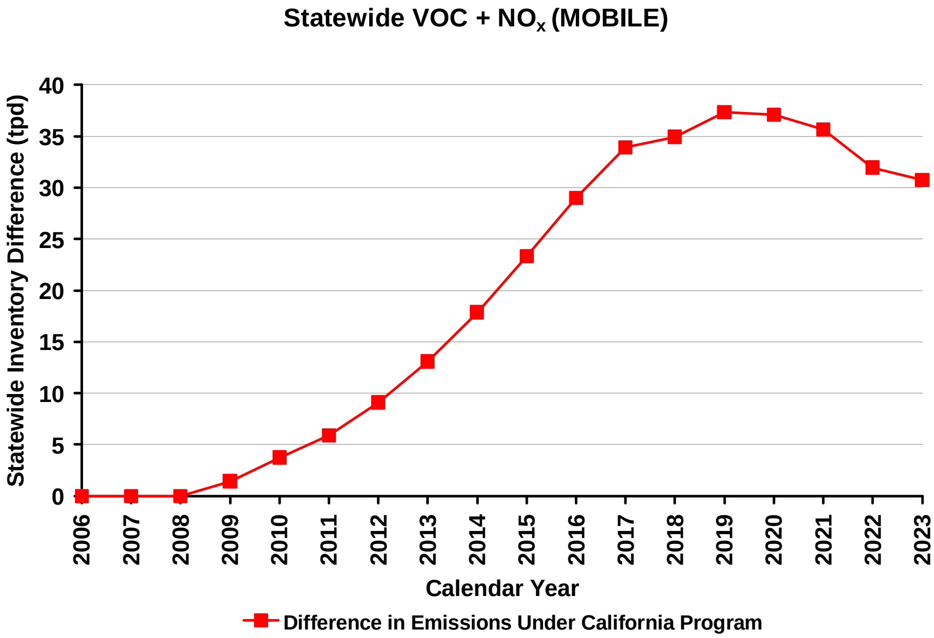

Figure 10. Change in statewide emissions of VOC + NO_x (MOBILE6.2 modeling) under the combined California Program, relative to emissions under the Federal Program.

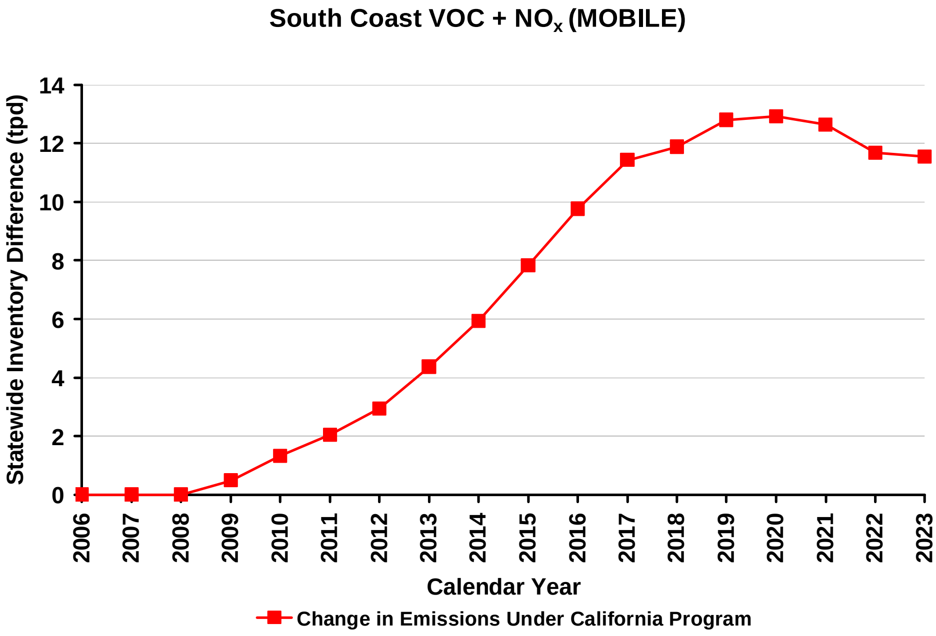

Figure 11. Change in statewide emissions of South Coast VOC + NO_x (MOBILE6.2 modeling) under combined California Program relative to Federal Program.

statewide basis and in the South Coast. The MOBILE6.2 results for the other critieria and toxic pollutants considered are also similar to those obtained with EMFAC 2007. (See Appendix G for additional results of MOBILE 6.2 modeling.)

IV. Conclusions

The California Program will have substantial impacts on the age and composition of the California vehicle fleet. Increased costs incurred by manufacturers in order to comply with the ZEV and GHG Standards will result in higher prices (and decreased demand) for new vehicles. This will lead to increased retention of used vehicles. Increased fuel economy for new vehicles that are sold will lead to an increase in vehicle miles traveled. The increased age of the vehicle fleet and the increased vehicle miles traveled resulting from the implementation of the California Program will result in substantially greater emissions of ozone precursors (VOC and NO_x) compared to emissions under the Federal Program. In addition, emissions of other criteria pollutants and air toxics, at both the statewide level and in the South Coast Air Basin, will generally be higher under the California Program than under the Federal Program (see Appendix E and Appendix F). The higher level of ozone precursor emissions under the California Program relative to the Federal baseline persists through the year 2023, at which time the South Coast Air Basin is required to achieve compliance with the National Ambient Air Quality Standard for ozone.

Thus, our results indicate that the California Program, in the aggregate, is less protective of public health than the Federal Program with respect to emissions of ozone precursors and several other criteria pollutants.

Appendix A. Compliance Plans and Cost Estimates[14]

Cost estimates were developed for a number of vehicle technologies capable of generating ZEV credits that have been or are likely to be considered by vehicle manufacturers and these were in turn used with the regulatory credit structure to determine the most likely manufacturer compliance pathway with the ZEV Standards. Compliance costs and associated compliance plans for the GHG Standards used in this analysis were developed previously by Sierra in Sierra's 2004 report and supplied to CARB at the time the GHG Standards were adopted.[15] As described below and in the documents submitted to CARB during the regulatory proceeding leading to adoption of the GHG Standards, we believe that the cost estimates used in this study likely understate the actual costs of compliance. Given that higher incremental costs for California vehicles would increase the magnitude of the fleet turnover effect (i.e., further reduce new vehicle sales and further increase retention of used vehicles), our use of this approach is conservative in that it also understates the likely differences in emissions under the California Program relative to the Federal Program.

Cost estimates for compliance with the ZEV standards represent incremental increases relative to gasoline-fueled vehicles certified to California's Super-Ultra Low Emission Vehicle (SULEV) standards. Although there are incremental costs for SULEVs relative to vehicles certified to federal emission standards, these costs were not quantified. Estimates of costs for compliance with the ZEV Mandate were developed for the three categories of vehicles capable of generating ZEV credits: (1) Partial Zero Emission Vehicles (PZEVs); (2) Advanced Technology Partial Zero Emission Vehicles (ATPZEVs), and; (3) Zero Emission Vehicles. Within these categories, separate cost estimates were developed for vehicles employing different technologies and for distinct vehicle classes (PC+LDT1 and LDT2).

In estimating the costs of vehicles required for the ZEV mandate, a number of different sources of information were used, including the recently published "Report of the ARB Independent

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[14] All costs referred to in this appendix are in year 2004 dollars. The NVMM escalates these to year 2005 dollars using the Consumer Price Index in order to be consistent with other data used in the modeling.

[15] Austin, T.C., et al., 2004, "Review of the August 2004 Proposed CARB Regulations to Control Greenhouse Gas Emissions from Motor Vehicles: Cost Effectiveness for the Vehicle Owner or Operator", Sierra Research Report No. SR2004-09-04, September, 2004.

Expert Panel 2007,"[16] confidential cost information supplied by individual auto manufacturers, and cost estimates provided by The Martec Group and Harbour Consulting. As described below, we elected to make conservative assumptions in preparing these cost estimates that likely underestimate the true costs.

A.1. PZEV Costs

Incremental cost estimates for PZEV technology of $350 and $500 per vehicle were used for PC+LDT1 and LDT2 vehicles, respectively. The PC+LDT1 value reflects the lower range of the cost data supplied by vehicle manufacturers, while the LDT2 value reflects the middle of that range. The use of the higher value for LDT2 reflects the higher expenses of achieving the zero-evaporative emission standard for PZEVs under the ZEV Mandate on vehicles with larger fuel tanks and the higher expenses of achieving the exhaust emission standard for PZEVs under the ZEV Mandate on larger vehicles with V8 engines.

A.2. ATPZEV Costs

Incremental cost estimates for Type C, D and E hybrid electric vehicles were $1,800, $2,200 and $5,500, respectively. These are based on the methodology documented in Sierra's 2004 report, with the estimates for Type D and E vehicles reflecting additional costs associated with high voltage electrical systems, nickel-metal hydride batteries, electric motors, and control systems. The costs of plug-in hybrid electric vehicles (PHEVs) with 10, 20 and 40 mile electric range in the PC+LDT1 category were estimated using component cost estimates provided by The Martec Group (the consulting firm relied on by CARB to provide cost information in support of the GHG rulemaking), and data from the report of the Independent Expert Panel. Incremental cost estimates ranged from about $10,500 for a 10 mile all electric range to about $15,000 for a 40 mile all electric range. Costs for LDT2 vehicles were again estimated by scaling the PC+LDT1 values by the relative sales-weighed average weights of 2003 model-year vehicles in these classes. Estimates for Type C, D and E hybrid electric vehicles are based on the methodology documented in Sierra's 2004 report, but have been updated to reflect the latest available cost data. The cost of plug-in hybrid electric vehicles (PHEVs) in the PC+LDT1 category has been

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[16] Kalhammer, F.R., et. Al, 2007, "Status and Prospects for Zero Emission Vehicle Technology, Report of the ARB Independent Expert Panel 2007" April 13, 2007.

estimated using component cost estimates provided by The Martec Group (the consulting firm relied on by CARB to provide cost information in support of the rulemaking for the GHG Standards), and data from the report of the Independent Expert Panel. Costs for LDT2 vehicles were estimated by scaling the PC+LDT1 values by the relative sales-weighed average weights of 2003 model-year vehicles in these classes.

A.3. ZEV Costs

We estimate a cost for Neighborhood Electric Vehicles ("NEVs") of $8,000, based on the nominal $8,000 price of NEVs produced by Global Electric Motors.[17] Because of their limited range and performance, NEVs are unlikely to be general replacements for conventional vehicles, although they would displace some conventional vehicle travel. Therefore, NEV purchase was viewed as a cost in addition to owning a conventional vehicle. Incremental costs for City Electric Vehicles were assumed to be equal to $13,122 which is the RPE of the vehicle battery, the cost of which ($8,150) was taken from the Independent Expert Panel and scaled using a multiplier of 1.61. This multiplier is used to adjust supplier costs to RPE and is derived from work performed by the U.S. Department of Energy.[18] Utility EV costs were assumed to be 2/3 that of a city electric vehicle given the respective range requirements of 50 and 75 miles.

The cost of full performance battery electric vehicles (FPBEV) was also estimated using data from Martec. In the case of pure electric vehicles, the cost of electric motors and power electronics is sometimes assumed to be offset by the cost savings associated with elimination of the internal combustion engine and transmission. However, using cost information provided by Martec and Harbour Consulting, the net cost of the non-battery changes is about $2,500 for a full-function EV with a 100 mile range. Using the simple assumption that only the battery cost need be accounted for, the incremental cost increase associated with a full-function EV is $26,400. If the range is reduced to 75 miles, the cost increase drops to about $19,900. For this study, we replaced the more realistic Martec battery cost estimates with the Expert Panel's average cost estimates for lithium-ion batteries scaled to RPE using the 1.61 multiplier, and then added the net cost of the non-battery changes described above. We used the lower volume cost

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[17] See http://www.gemcar.com/affordability/default.asp?ID=355

[18] Vyas, a., Santini, D., and Cuenca, R., 2000, "Comparison of Indirect Cost Multipliers for Vehicle Manufacturing," Argonne Naional Laboratory, April, 2000.

estimate through the 2012 model-year and then linearly transitioned to the high volume cost estimate for 2015 and later model-years. This resulted in a near term incremental cost estimate of about $23,000 for a FPBEV and a longer term incremental cost of about $17,000.

The incremental cost of fuel cell electric vehicles (FCEVs) was estimated using the average of the Expert Panel's best case current and 2015 estimates for fuel cell system costs in high volume production, and an assumed stack rating of 100 kW. These values were marked up to RPE using a 1.61 multiplier. The current best-case costs were used through the 2012 model-year, and then linearly transitioned to the 2015 value in that year and beyond. Thus, the incremental costs assumed for FCEVs were about $60,000 in the short term and about $11,000 in the longer term.

A.4. Summary of Cost Estimates

Cost estimates for all of the ZEV vehicle technologies considered are shown in Table A-1 for the PC+LDT1 and LDT2 categories, respectively.

Table A-1. Cost Estimates for ZEV Program Vehicles

Type	Credit Level	PC+LDT1	LDT2
PZEV	Bronze	350	500
Type C HEV	Silver	1,800	2,718
Type D HEV	Silver	2,200	3,322
Type E HEV	Silver	5,500	8,305
PHEV10	Silver	10,576	15,970
PHEV20	Silver	11,654	17,597
PHEV40	Silver	14,977	22,616
NEV	Gold	8,000	8,000
Type 0 ZEV	Gold	8,748	8,748
Type 1 ZEV (CEV)	Gold	13,122	19,813
Type 2 ZEV (FPBEV)	Gold	23,366/16,732[a]	35,282/25,266[a]
Type 3 ZEV (FCEV)	Gold	60,375/10,868[a]	91,166/16,410[a]

[a] First value represents near term costs while second reflects long term cost.

A.5. Per-Credit Cost Estimates and Manufacturer Compliance Strategies

Using the cost estimates in Table A-1 and the information regarding ZEV credits generated by vehicles utilizing various technologies from the ZEV regulations, we estimated the effective cost of each technology in terms of the dollars required per ZEV credit generated. These results are shown in Table A-2.

PZEVs generate ZEV credits at the lowest dollar per credit value of any of the technologies considered in both the PC+LDT1 and LDT2 categories. Given this and the fact that PZEVs are conventional, gasoline-powered vehicles, we expect that manufacturers will generate the maximum amount of Bronze ZEV credits allowed under the regulations. Turning to vehicles capable of generating Silver ZEV credits, Table A-2 indicates that, except during the period from 2009 through 2011, Type D HEVs provide credits at the lowest per-credit cost. During 2009 to 2011, PHEV credit costs are lower owing to the credit multipliers provided in the ZEV regulations. However, as noted by the Independent Expert Panel, batteries capable of handling the number of deep discharge cycles required for PHEV applications are not currently commercially available. Given this, and the fact that the incremental cost of Type D HEVs is lower than that of PHEVs and that Type D HEVs ultimately yield Silver ZEV credits at a lower per vehicle cost than PHEVs in later years, we have assumed that manufacturers would select Type D HEVs over PHEVs for generating Sliver ZEV credits.

A similar analysis for technologies capable of generating Gold ZEV credits indicates that CEVs generate credits at the lowest per-credit cost in the near term while FCEVs do so in the longer term. Further, through 2014, the cost of generating Silver ZEV credits with Type D HEVs will be at least 50% lower than the cost of generating Gold ZEV credits with any technology. Given this, we have assumed that manufacturers will elect to pursue the Alternative Compliance Path provided in the ZEV Mandate and use extra Silver credits generated by Type D HEVs to fulfill their ZEV obligation as provided for under the regulation. Beginning in 2015, FCEVs are estimated to provide Gold ZEV credits at a lower per credit cost than Type D HEVs. However, that estimate is based on what appear to be highly optimistic “best-case” estimates by the Independent Review Panel of the costs of fuel cell systems in 2015 and the Panel estimated that high volume production of fuel cell vehicles would be delayed relative to CARB’s previous expectations. Therefore, we assumed that manufacturers would continue to pursue the Alternative Compliance Path through the 2017 model-year. Beyond 2017, we made the very optimistic assumption that manufacturers would be capable of complying with the requirements to generate Gold ZEV credits using FCEVs. Again this assumption was conservative in that it likely understates the actual costs of compliance with the California Program and therefore understates the emissions increases associated with the California Program relative to the Federal Program.

Table A-2. Dollars per ZEV Credit during the period 2009-2023

Type	Credit Level	PC+LDT1	LDT2
PZEV	Bronze	1,750	2,500
Type C HEV[a]	Silver	4,500	6,795
Type D HEV	Silver	3,667/4,889	5,537/7,382
Type E HEV	Silver	7,857/10,000	11,864/15,100
PHEV10	Silver	1,738/5,630	2,624/8,501
PHEV20	Silver	1,765/5,681	2,665/8578
PHEV40	Silver	2,700/6,408	3,031/9677
NEV	Gold	53,333	53,333
Type 0 ZEV	Gold	8,748	8,748
Type 1 ZEV (CEV)	Gold	5,249/6561	7,925/9,907
Type 2 ZEV (FPBEV)	Gold	5,577/7,789	8,422/11,761
Type 3 ZEV (FCEV)	Gold	3,623/20,125	5,470/30,389

[a] Type C HEVs are allowed to generate ZEV credits only through the 2011 model-year.

Appendix B. New Vehicle Market Model

This appendix provides information regarding the New Vehicle Market Model.

B.1. Conceptual Approach: Nested Logit Model

Logit discrete choice analysis provides a method for predicting consumer choices, and therefore demand, based on previously observed consumer behavior and other assumptions about demand (see, e.g., Ben-Akiva and Lerman 1985). The most basic logit model, also referred to as the simple logit, groups all product alternatives together and therefore allows only limited patterns of own-price and cross-price elasticity between different alternatives. This limitation is often referred to as the "Independence of Irrelevant Alternatives" ("IIA") problem. The nested logit model builds on this simple framework, while allowing for a much richer pattern of cross-substitution between different alternatives through the nesting structure.

B.1.1. Basic Framework

In our new vehicle market model, consumers choose among a set of vehicle models, and may also choose not to purchase a vehicle at all. For alternative *i*, the utility that a given consumer obtains from choosing that alternative can be written as a function of an alternative-specific parameter and the price for the alternative:

$$U_i = a_i - bP_i + e_i \tag{1}$$

Alternative "0" is defined as the no-purchase alternative, and the remaining alternatives represent decisions to purchase individual vehicle models. The parameter a_i measures the attractiveness of good i to consumers. We assume that the price for the outside good is zero. P_i is the price of alternative i, and b is a positive coefficient. The random error terms e_i are assumed to be distributed as a multivariate generalization of the standard extreme value distribution.

The potential purchaser is assumed to choose the alternative that yields the highest utility, taking into account both the deterministic and random components of utility. Given the logit demand assumptions, we determine the expected market share for each vehicle model. Conditional upon the consumer's decision to purchase a vehicle model within a vehicle group (or "nest") A (as described below), the expected share for vehicle model alternative i can be written as:

$$s_{i|A} = \frac{\exp((a_i - bP_i)/l_A)}{\sum_{j \in A} \exp((a_j - bP_j)/l_A)} \quad \textbf{(2)}$$

where l_A is the "nesting parameter" for the appropriate vehicle group, or "nest" (as described below).[19]

B.1.2. Nesting Assumptions

Our logit model assumes the nesting structure shown in Figure B-1. We divide the choice problem first into the decision of whether to buy a new vehicle. Conditional upon the choice to purchase a new vehicle, consumers choose the vehicle type—in this case, passenger cars, pickup

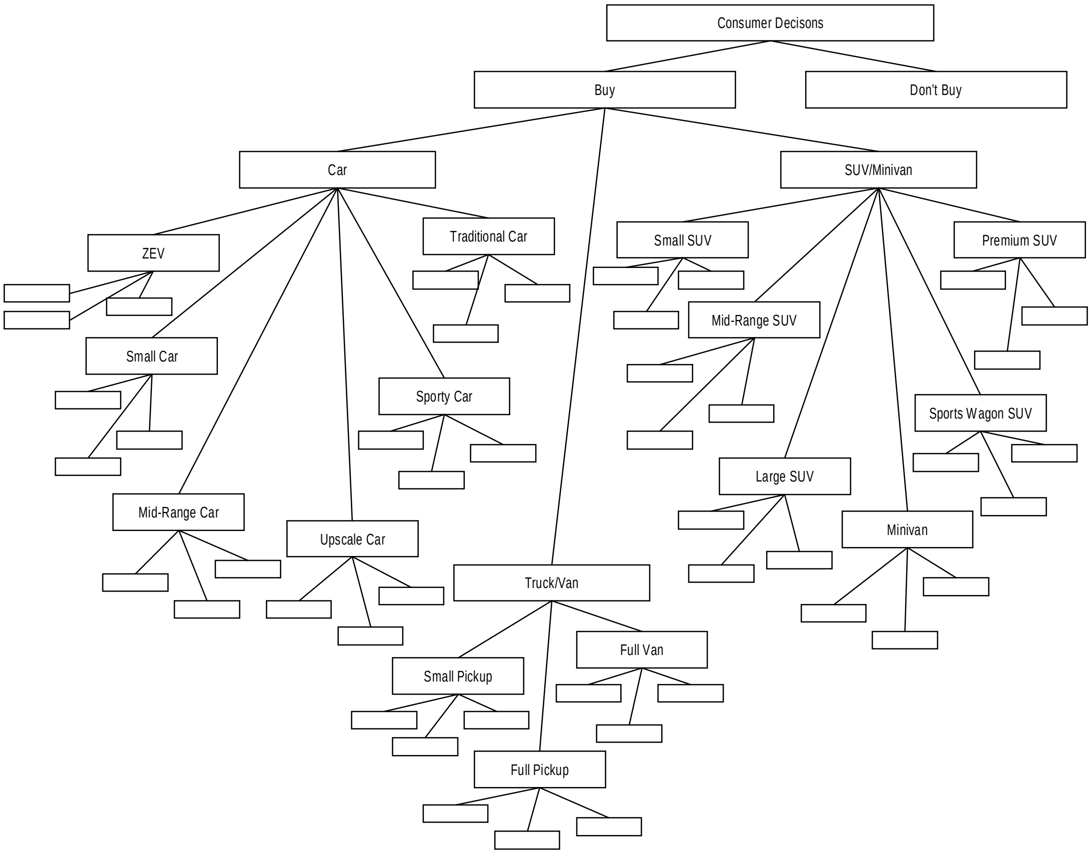

Figure B-1. Nesting structure for NVMM

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[19] Because terms that are constant across all alternatives do not affect the choice of alternatives, it is common to normalize the alternative-specific term a_i. As a normalization rule, we set a_i equal to zero for one vehicle model. Adding or subtracting a common amount to all the a_i terms leaves the choice of alternatives unchanged, so any other normalization rule would yield identical results.

trucks or full-size vans, and SUVs or minivans. Conditional on the choice of vehicle type, consumers choose the vehicle class—for example, small cars or mid-range cars (among others) in the passenger car group. Conditional on the vehicle class (e.g., mid-range car, small SUV, etc.), consumers choose one of the individual vehicle models available. The bottom level of the nesting structure includes over 200 vehicle models from which consumers may choose.

The market model allows the utility that consumers derive from the purchase of different models to depend on the vehicle category and class via the nesting parameters (l_A), which take values between zero and one.[20] One nesting parameter applies to the purchase decision (buy or don't buy); another nesting parameter applies to the choice of vehicle type; and a third applies to the choice of vehicle classes. The nesting parameter for the purchase decision must be at least as large as the nesting parameter for vehicle type. For each nest, the nesting parameter must be at least as large as the nesting parameter for all vehicle nests contained within the "parent" nest. The nesting structure implies that vehicles within one group are closer substitutes for each other than they are for vehicles in different groups. The cross-price elasticities between vehicles within the same group are therefore higher than the cross-price elasticities for vehicles in different groups.

As noted above, one advantage of the nested logit model over the simple logit model is that it provides for a richer pattern of own- and cross-price elasticities. In the nested logit model, the IIA property need not hold across groups. That is, the ratio of the share for a particular car model in one bottom-level nest to the share of a vehicle in a different bottom-level nest, for example, depends not only on the characteristics of those two vehicle models, but also on the substitution patterns implied by the nesting structure and nesting parameters. The nesting parameters therefore enrich the simple logit model. If all nesting parameters equal one, then the nested logit model becomes a simple logit model.

The inclusive value term I_A for bottom-level group A (the vehicle class) is defined as:

$$I_A = \ln\left[\sum_{j \in A} \exp((a_j - bP_j)/l_A)\right] \tag{3}$$

The inclusive value term I_X for the top-level group X (the vehicle type) is defined as:

$$I_X = \ln\left[\sum_{A\in X} \exp(I_A l_A / l_X)\right] \tag{4}$$

Finally, the inclusive value term I_{Buy} for the purchase alternative is defined as:

$$I_{buy} = \ln\left[\sum_{X} \exp(I_X l_X / l_{buy})\right] \tag{5}$$

The share of the bottom-level group A in purchases within the top-level group X to which A belongs can be written as:

$$s_{A|X} = \frac{\exp(I_A l_A / l_X)}{\sum_{B\in X} \exp(I_B l_B / l_X)} \tag{6}$$

The share of top-level group X in total purchases can be written as:

$$s_{X|buy} = \frac{\exp(I_X l_X / l_{buy})}{\sum_{Y} \exp(I_Y l_Y / l_{buy})} \tag{7}$$

The logit framework gives an expression for the share of potential buyers who choose to purchase a vehicle:

$$s_{buy} = \frac{\exp(I_{buy} l_{buy})}{\exp(I_{buy} l_{buy}) + \exp(a_0)} \tag{8}$$

where a_0 is the value derived by the consumer from a no-purchase decision.

The unconditional share for alternative i can be written as the product of the purchase probability and the conditional probabilities:

$$s_i = s_{buy} s_{X_i|buy} s_{A_i|X_i} s_{i|A_i} \tag{9}$$

where A_i is the bottom-level group to which i belongs and X_i is the top-level group to which A_i belongs.

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[20] The nesting parameters are sometimes called “inclusive value coefficients.”

B.2. Market Simulation

In a simple logit model, the own-price elasticity of demand for alternative *i* can be written as:

$$h_i = -bP_i(1-s_i) \qquad \textbf{(10)}$$

where s_i is the unconditional share of alternative *i* (i.e., its share over all potential consumers, not only those who choose to purchase a new vehicle).

In a nested logit model, the own-price elasticity of demand for alternative *i* is more complicated, including terms that reflect substitution possibilities within the bottom-level group, across bottom-level groups that are within the same top-level group, and across top-level groups. Taking the natural logarithm of Equation 9, and differentiating with respect to the natural logarithm of P_i yields an expression for the own-price elasticity for the nested logit model:

$$h_i = \frac{\partial \ln(s_{buy})}{\partial \ln(P_i)} + \frac{\partial \ln(s_{X_i|buy})}{\partial \ln(P_i)} + \frac{\partial \ln(s_{A_i|X_i})}{\partial \ln(P_i)} + \frac{\partial \ln(s_{i|A_i})}{\partial \ln(P_i)} \qquad \textbf{(11)}$$

The aggregate price elasticity of demand can be calculated by increasing the prices of all goods by a common percentage, finding the percentage change in total demand, and taking the limit of this percentage change in demand as the percentage change in price goes to zero. The aggregate price elasticity of demand can be written as

$$E = -b\,\overline{P}(1-s_{buy}) \qquad \textbf{(12)}$$

where $\overline{P}$ is the share-weighted average price of new vehicles.

We assume that the motor vehicle market is characterized by Bertrand competition where each manufacturer sets prices to maximize its overall profits, taking into account the fact that it is a multi-product firm. In a Nash equilibrium for this Bertrand competition, the profit-maximizing price for a single-product firm can be written as follows (where MC_i is the marginal cost for alternative *i*, assumed to be constant):[21]

$$\frac{P_i - MC_i}{P_i} = \frac{1}{h_i}\text{, or } P_i = MC_i + \frac{P_i}{h_i}. \qquad \textbf{(13)}$$

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[21] See, e.g., Carlton and Perloff (1999) for a discussion of the Bertrand-Nash assumptions.

If one observes P_i, then knowing either the marginal cost or the elasticity provides enough information to calculate the other.

For a multi-product firm (as is the case for all major auto firms in the United States), the pricing equations include additional terms that reflect the unit profits on other products made by the firm and the cross-elasticities of demand between good i and these other products. The basic logic is that as the price of good i increases, some of the lost sales of that good will be replaced by increased sales of other goods sold by the same firm. Our model takes these effects into account. Additionally, we modified the methodology to take into account how the requirements under the ZEV Mandate would affect manufacturers' profit maximizing pricing decisions.

B.3. Solving for Parameters

As described above, the nested logit choice framework provides a method to estimate consumer demand for differentiated products, using as data the prices and parameters that measure the relative attractiveness of each product. Using the logit framework, we solve simultaneously for the beta parameters and "alternative-specific" parameters that are consistent with the observed market shares and prices. If two products in the same group have the same price but different market shares, then the one with the higher share must be more attractive to consumers. Similarly, if two products in the same group have the same market share but different prices, then the one with the higher price must be more attractive to consumers, since consumers are observed to pay a premium for it.

We use the logit framework to estimate alternative-specific parameters for each vehicle model. We make assumptions concerning the nesting parameters, the aggregate price elasticity of demand, and the price elasticity of demand for one specific alternative. Given the structure of our nested logit model, these assumptions, the observed prices, and the observed market shares are sufficient to derive estimates of the alternative-specific parameters (including those for the outside good).

The model estimates marginal costs for each vehicle model based on the profit-maximization conditions outlined above. This condition assumes that each manufacturer chooses the price for a given vehicle that will maximize its profits, taking into account the new vehicle marginal costs, the sensitivity of consumer demand to changes in vehicle prices, and the availability to consumers of substitute vehicles offered by that manufacturer and its competitors. The model uses vehicle prices and assumptions about consumer responses to changes in those prices to calculate marginal costs that are consistent with both profit-maximizing behavior and the observed market shares. Marginal costs for each vehicle are calculated based on each vehicle's calculated elasticity.

B.4. Estimating Consumer Valuations of Vehicle Attributes

Once the alternative-specific parameters implied by the observed vehicle shares and prices are calculated, we estimate the extent to which consumers value each vehicle attribute through a "second-stage" regression for the alternative specific parameters. For each vehicle in the sample, the alternative specific parameters are regressed on vehicle characteristics such as horsepower, weight, and fuel economy.

We assume each vehicle's alternative-specific parameter depends upon the vehicle's model and attributes according to the following model:

$$a = jX + + d_{year} D_{year} + f_{model} D_{model} + e \qquad \textbf{(14)}$$

where

a is the alternative-specific coefficient,

X are vehicle characteristics,

D_{year} are dummy variables corresponding to vehicle model years,

D_{model} are dummy variables corresponding to the vehicle model,

e is an error term capturing unobserved characteristics, and

j , d_{year}, and f_{model} are estimated parameters.

B.4.1. Effects of California Program

The California Program will lead to higher vehicle costs and increased fuel economy (miles per gallon) for various models. The marginal costs of covered vehicles for each manufacturer are adjusted to reflect the relevant cost increases for covered vehicles. The new vehicle market model calculates each manufacturer's response to the additional costs in each year.

B.4.2. Calculating Quality-Adjusted Price Changes

Given the assumptions of the nested logit model, the expected maximum utility available for a given set of prices, automobile models, and parameters can be written as:

$$U_{total} = \ln(\exp(I_{buy}\, l_{buy}) + \exp(a_0)) \qquad \textbf{(15)}$$

The consumer welfare (per potential purchaser) is calculated as the ratio of the maximum expected utility to the price coefficient:

$$\text{Consumer Welfare} = \frac{U_{total}}{b} \qquad \textbf{(16)}$$

As defined above, the inclusive value for the "buy" alternative depends on the prices and alternative-specific constants for each car model.

This utility can be calculated twice--first with the prices and parameters for the baseline conditions, and again with the prices and parameters for the California Program. That is:

$$\begin{aligned} U_{total}^{base} &= U_{total}(P^{base}, a^{base}) \\ U_{total}^{CAL} &= U_{total}(P^{CAL}, a^{CAL}) \end{aligned} \qquad \textbf{(17)}$$

To calculate the quality-adjusted aggregate percentage price change for the California Program analyzed relative to the baseline, we solve for a common percentage price change that, if applied to the base prices, with the base parameters, would yield the same utility as under the relevant regulatory scenario. That is:

$$\text{find } q \text{ such that } U_{total}^{CAL} = U_{total}((1+q)P^{base}, a^{base}) \qquad \textbf{(18)}$$

B.5. Specific Implementation Parameters and Data

B.5.1. Vehicle Sales

We use California-specific vehicle sales data from R.L. Polk and Company to determine the market share for each vehicle model, aggregated across trim levels, for the years 2001-2005. For each model year, we use sales over the period October – September to reflect as accurately as possible the timing of new model availability. If a vehicle sold less than 500 units in California, the vehicle model was eliminated from the dataset.[22] To avoid under-valuation of models that were either discontinued or that were first introduced during the middle of a model year because the actual sales would not be good estimates of their annual sales, we eliminated observations where the number of vehicles sold was dramatically smaller than in the previous or subsequent year for the same model.

B.5.2. Vehicle Prices

We use data on transaction prices for each model from J.D. Power and Associates for the United States and specifically for California. The transaction prices are sales weighted and reflect the different prices charged for different trim levels.

B.5.3. Vehicle Fuel Economy Data and Other Vehicle Characteristics

We use vehicle characteristic data from Ward's to determine the fuel economy of each model. The fuel economy used in this analysis is the EPA adjusted combined (city and highway combined) miles per gallon. We also rely on data from Ward's for data on other vehicle attributes, including engine size, number of cylinders, curb or test weight, horsepower, length, and height.

B.5.4. Categorization of Vehicle Models into Nests

We use vehicle categorizations from the 2005 Automotive News Market Data Book to define the vehicle nesting structure depicted in Figure B-1. Where the appropriate category for a particular model could not be determined based on the 2005 Automotive News Market Data Book, we used older Automotive News Market Data Books or Ward's categorizations.

B.5.5. Price Elasticity

Consistent with various literature sources, we assume an aggregate elasticity for the new vehicle market of –1.0.[23] We set the own-price elasticity of the "normalized" vehicle model (whose

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[22] The one exception to this is the case of pure ZEVs. We utilize the same sales data on the Toyota RAV4 EV that was used in our previous analysis (see NERA/Sierra, 2003, Attachment B), with the exception that, rather than assuming initially an inflated demand for ZEVs, we use the RAV 4 EV sales data to develop initial demand for ZEVs. We then linearly increase the attractiveness of ZEVs each year in two phases: first from 2005 to 2009, then from 2009 to 2018. By 2018, the attractiveness of ZEVs in our model is such that, all else being equal, the demand for ZEVs would be 40 times greater than the demand for the RAV4 EV.

[23] See, for example, Gruenspecht (2000).

alternative-specific parameter is normalized to zero) to be –4.0, which is consistent with various other literature estimates of individual model own-price elasticities.[24]

The nesting parameters for nested logit models represent the similarity between choices for vehicles falling within the same "nest." The nesting parameters influence the relative substitutability within each nest, and also between different nests. Nesting parameters may take any value between zero and one, with lower values indicating greater similarity between the alternatives within the respective nest. For the "Buy" nest we use a nesting parameter equal to 0.9, for vehicle types we use a nesting parameter equal to 0.6 and for vehicle classes we use a nesting parameter equal to 0.3.

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[24] See, for example, Berry, Levinsohn, and Pakes (1995).

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Appendix C. Scrappage Model

This appendix provides information on the scrappage model used in this study.

C.1. Vehicle Prices and Scrappage Behavior

The idea that economic as well as technical considerations can influence the life spans of durable capital goods such as motor vehicles has long been recognized. Specifically, the link between a vehicle's market value and its service lifetime was first explicitly recognized more than three decades ago. This logic is straightforward: a vehicle is retired from service (or scrapped) when it is no longer worth the expense of keeping it in working condition. That is, when the difference between the vehicle's resale price (in working condition) and the cost of keeping it in this condition is less than its scrap value, the vehicle is scrapped.

Building on this basic insight, early research by Walker (1968) and Parks (1977) investigated the influence of a vehicle's market value, as well as characteristics such as its age, on the vehicle owner's decision to retire the vehicle from service rather than maintain it in working condition. Both authors present statistical evidence of the influence of vehicle prices on the scrappage rates of used vehicles of different model year vintages and ages, demonstrating that variation in automobile prices exerts a detectable influence on scrappage rates of used cars. Berkovec (1985) later incorporated the framework developed in this earlier research in a model encompassing new automobile production and sales activity, vehicle pricing behavior, and scrappage of used autos.

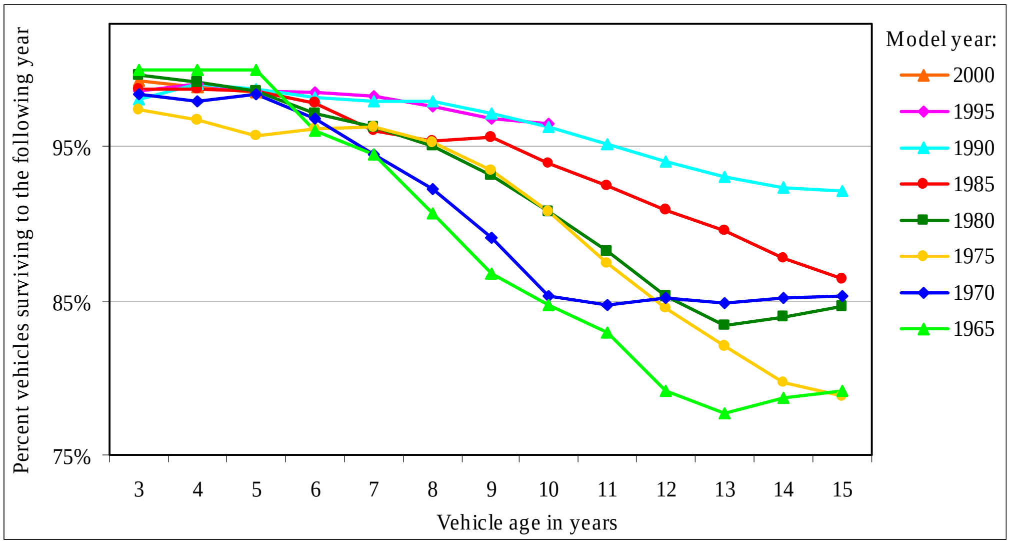
Also drawing on previous results, Gruenspecht (1982) recognized that the connection between new and used vehicle prices—whereby rising prices for new models exert an upward "pull" on resale prices for used vehicles—meant that changes in prices for new automobiles could influence scrappage decisions by older cars' owners. As a result, he hypothesized, emissions regulations that raised production costs and sales prices of *new* vehicles might retard the scrappage and replacement of older models sufficiently to offset the reduction in conventional emissions from introducing cleaner new models into the vehicle fleet.

Gruenspecht's research produced evidence that the increase in new car prices resulting from manufacturers' compliance with the 1980-81 federal emissions standards could be sufficient to have this effect. This study can be considered an updated version of Gruenspecht's statistical model relating used vehicles' scrappage rates to new vehicle prices.

C.2. Model Used in this Study

The vehicle scrappage model used here is based on well-established economic theory and empirical evidence on the response of owners' decisions about retiring (or "scrapping") used vehicles to changes in economic factors. The model estimates a relationship between scrappage or retirement rates for vehicles of different model year vintages at each age during their lifetimes and macroeconomic conditions (e.g., unemployment rate), factors affecting total motor vehicle ownership and use, and other factors influencing scrappage rates of used vehicles. This relationship was developed using various data and statistical procedures appropriate for these data.

This study estimates a "reduced-form" scrappage model using aggregate scrappage rates for the individual vehicle model years making up the U.S. passenger vehicle fleet over the 1970-2005 period (rather than the scrappage rates for individual vehicle models originally employed by Gruenspecht). Updating results from Gruenspecht's earlier model is necessitated by dramatic increases in the expected lifetimes and average ages of passenger vehicles that have occurred since his original work was published. Figure C-1, which displays yearly survival rates of vehicles manufactured during different model years, illustrates these changes.



Source: R.L.Polk & Company.

Figure C-1. Vehicle Survival Rates by Age and Model Year

C.2.1. Basic Theory of the Model

A vehicle's owner will retire the vehicle from service and sell it for its scrap value if its value in working condition exceeds its scrap value by less than the expected cost of repairs necessary to maintain it in working condition. Since the expected cost of these repairs depends on how long a vehicle has been in service as well as on the materials and manufacturing technology employed when it was produced, the probability that it will be scrapped is likely to depend on both its original model year and its age. To some extent, a vehicle's age may simply be a surrogate measure of its accumulated usage, although its age per se may also affect its sale value in working condition and thus the likelihood that it will be retired.

At the aggregate or fleet-wide level, the scrappage rate among a "cohort" of vehicles in service (measured by the proportion of those in service at the beginning of a year that are retired or scrapped before it ends) will thus depend on both their model year and their age during that year. The scrappage rate also will reflect the effects of vehicles involved in motor vehicle accidents that remove vehicles from service. Because prices for new vehicles are in turn an important influence on prices for used vehicles of different ages, scrappage rates for vehicles of each model year in the fleet during a calendar year are likely to be affected by changes in new vehicle prices and the myriad factors that determine them (including manufacturers' costs for complying with government regulations).

Finally, scrappage rates for all model years in service are also likely to be affected - although not necessarily uniformly - by changes in other economic variables such as employment or personal incomes. This occurs because keeping used vehicles in service longer provides a temporary mechanism for accommodating increases in total demand for motor vehicle travel that result from changes in economy-wide conditions. Extending the service lifetime of a used vehicle in order to accommodate increased travel demand is accomplished by deferring its retirement beyond the age at which it would otherwise have occurred, a response that reduces the aggregate scrappage rate for vehicles of various ages.

C.2.2. Model Variables and Data Sources

The data used to develop this model of these empirical relationships include scrappage rates calculated from U.S. annual vehicle registration data for the years 1970 through 2005. During each calendar year of this period, we use registration data for passenger vehicles reported by R.L.

Polk & Company to calculate scrappage rates for vehicles of ages 4 through 14 years, and an overall scrappage rate for vehicles that are 15 years and older.[25] The scrappage rate is measured as the decrease in registered cars over the year divided by the number of registered cars at the beginning of the year.[26] While the specific types of vehicles included in these registration data - and thus in the scrappage rates used to develop this model - vary over the extended period covered by this study, for most of those periods they closely match those encompassed by the GHG and ZEV Standards, and the federal government's Corporate Average Fuel Economy ("CAFE") standards.

Each of the scrappage model variables is summarized below, along with the specific rationale for including it and a brief description of the specific data source used to measure it.

1. *Vehicles per Driver (Lagged).* This variable represents the average number of vehicles per licensed driver in the *previous* year. It is intended to measure the effect of previously postponed scrappage and replacement of older vehicles due to macroeconomic and other conditions on scrappage in subsequent periods; higher values of this lagged variable are expected to lead to increased scrappage in the current year. The measure is calculated from the R.L. Polk data on vehicles in each year (as discussed above) and information on licensed drivers in each year obtained from the U.S. Federal Highway Administration in its annual *Highway Statistics*.

2. *New Car Price-Age Interactions.* This set of variables is measured as the interaction of the average new car price (in real terms) times the set of dummy variables for vehicle age. Average new car price is measured as the average real (2005 dollar) price, based upon average nominal expenditure per car reported by the Bureau of Economic Analysis and conversion of 2005 dollars using the CPI

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[25] R.L. Polk reports that prior to the 1993 release, which as noted below is for registrations as of July 1, 1992, it double-counted used vehicles sold by a resident of one state to a resident of a different state that were then simultaneously registered in two states. This double-counting for some registered vehicles was corrected for the 1993 release and subsequent data releases. R.L. Polk did not adjust data from prior years when it made the correction. To avoid calculating inaccurate scrappage rates for years affected by this change in methodology, we dropped observations whose scrappage rates could be calculated using different methods (three years worth of observations). We also allowed for a structural change related to the effect of the lagged vehicles per driver on scrappage rates by interacting it with a dummy variable that took the value of one for observations after 1992.

[26] R.L. Polk reports registrations as of July 1 of each year. To calculate the scrappage rate for each calendar year (i.e., over the period from January 1 to December 31), we calculated two scrappage rates, one based upon the change from the previous year to the current year (e.g., for 2000, from July 1, 1999 to July 1, 2000) and one based upon the change from the current year to the subsequent year (e.g., for 2000, from July 1, 2000 to July 1, 2001); the scrappage rate we used for each year was the average of these two values.

deflator reported by the Bureau of Labor Statistics (as presented in the Economic Report of the President (2006)).

3. *Unemployment Rate.* This variable measures the effect of macroeconomic conditions on vehicle scrappage; higher unemployment during periods of slow economic growth or recession may cause vehicle owners to delay scrappage and replacement of older vehicles. It is measured by the annual unemployment rate among males aged 19-65 years of age, as reported by the U.S. Bureau of Labor Statistics.

4. *Fatal Crashes per VMT.* This variable measures scrappage due to accidents. The variable is calculated as the number of passenger cars involved in crashes in which a person is killed, divided by the annual vehicle miles traveled. This variable is intended to measure vehicles lost in major accidents. The data were obtained from the National Highway Traffic Safety Administration.

Recognizing the “panel” nature of the data used to develop it, the scrappage model also includes categorical, age specific variables (termed “fixed effects” in statistical analysis).

C.2.3. Model Form and Estimation

The specific mathematical form of the scrappage model employs the measure

$$\ln\left(\frac{s}{1-s}\right) \qquad \textbf{(1)}$$

as its dependent variable, where s is the aggregate scrappage rate for vehicles of an individual model year at a specific age, and ln(.) denotes the natural logarithm. This transformation of the scrappage rate, sometimes called the “logit” of the scrappage rate, converts a measure bounded by the values zero and one—and in practice varying over a much narrower range—to one spanning a wider range of values. Using the transformed value of the scrappage rate as the model’s dependent variable allows the estimated coefficients to exhibit desirable statistical properties. (Note that the results of the regression model using the logit transformation can be transformed back into an estimated relationship between the scrappage rate itself and the explanatory variables.)

C.3. Statistical Results

The resulting model performs well in explaining variation among scrappage rates across the wide range of model years and extended historical period spanned by the underlying data. Table C-1 presents the statistical coefficient estimates and other results of the estimated model in

Table C-1. Coefficient estimates for model of age-specific vehicle scrappage rates.

Dependent variable	ln[s/(1-s)]	R-squared	0.9963
Sample period	1970-1990, 1994-2005	F(34,351)	2901.1
Number of observations	385	Root MSE	0.1839

Variable	Coefficient	Std. Error	t-Statistic
Age dummy - 4 yrs	(dropped)		
Age dummy - 5 yrs	1.1443	0.4285	2.67
Age dummy - 6 yrs	1.8092	0.431	4.2
Age dummy - 7 yrs	2.6862	0.4334	6.2
Age dummy - 8 yrs	3.8674	0.4363	8.86
Age dummy - 9 yrs	4.7986	0.4402	10.9
Age dummy - 10 yrs	5.4719	0.4452	12.29
Age dummy - 11 yrs	5.6934	0.4518	12.6
Age dummy - 12 yrs	5.5689	0.4632	12.02
Age dummy - 13 yrs	5.0569	0.4747	10.65
Age dummy - 14 yrs	4.352	0.4869	8.94
Age dummy - 15 and older	4.1254	0.4995	8.26
New car price × Age dummy - 4 yrs	0.0238	0.0198	1.2
New car price × Age dummy - 5 yrs	-0.0234	0.0198	-1.19
New car price × Age dummy - 6 yrs	-0.0363	0.0197	-1.84
New car price × Age dummy - 7 yrs	-0.0618	0.0197	-3.14
New car price × Age dummy - 8 yrs	-0.1037	0.0197	-5.27
New car price × Age dummy - 9 yrs	-0.1326	0.0197	-6.74
New car price × Age dummy - 10 yrs	-0.15	0.0197	-7.61
New car price × Age dummy - 11 yrs	-0.1474	0.0199	-7.42
New car price × Age dummy - 12 yrs	-0.1307	0.02	-6.54
New car price × Age dummy - 13 yrs	-0.0972	0.0202	-4.82
New car price × Age dummy - 14 yrs	-0.0571	0.0205	-2.79
New car price × Age dummy - 15+ yrs	-0.0434	0.0208	-2.09
Model year dummy - 1950's	-10.3183	0.8248	-12.51
Model year dummy - 1960's	-10.4191	0.8136	-12.81
Model year dummy - 1970's	-10.2789	0.8067	-12.74
Model year dummy - 1980's	-10.4061	0.8076	-12.89
Model year dummy - 1990's	-10.5713	0.7902	-13.38
Model year dummy - 2000 and later	-9.9982	0.7874	-12.7
Unemployment rate	-6.7999	1.0061	-6.76
Vehicles in fatal crashes/VMT	0.2697	0.0407	6.63
Last period vehicles per driver	7.7761	1.0999	7.07
Last period vehicles per driver × Post 1992 dummy	0.1722	0.0952	1.81

detail. The signs of the estimated coefficients for all of the model's variables reflect the effects on scrappage rates anticipated in the preceding discussion. Most of the coefficient estimates for vehicle age and new car price-age interactions are statistically significant; all have the expected sign except for the coefficient on the age 4 x new vehicle price interaction variable, which is positive but not significant.

The model shows the sensitivity of scrappage rates to changes in new vehicle prices. Rising prices for new models significantly reduce scrappage rates for vehicles five years of age and older. This model allows new vehicle prices to have different effects on scrappage of used vehicles of different ages. The effect gradually increases with age until age 10, and then slightly decreases. Table C-2 shows the elasticity of scrappage for 2004 with respect to new car price calculated at the mean scrappage rate for each age group.

Table C-2. Scrappage elasticities with respect to new car price by car age.

	Age-Specific Scrappage Rates	Elasticity of Scrappage with Respect to New Car Price
Age 4	0.0136	0.5073
Age 5	0.0144	-0.4997
Age 6	0.018	-0.7712
Age 7	0.0213	-1.3093
Age 8	0.0244	-2.1889
Age 9	0.0288	-2.7853
Age 10	0.0352	-3.1296
Age 11	0.0407	-3.0596
Age 12	0.048	-2.6916
Age 13	0.0549	-1.9875
Age 14	0.0672	-1.153
Age 15 and up	0.0787	-0.8648

C.4. Using the Scrappage Model

We use the estimates of the effects of changes in prices (adjusted for utility as described in Appendix B) due to the California Program in conjunction with the age-specific effects of new vehicle prices on scrappage rates produced by this model to simulate future changes in the age distribution of these vehicles in California. Specifically, we calculate the changes in scrappage rates for vehicles of each age from four to 15+ predicted by the model's coefficients to result from the specified increases in the average sales price of new vehicles. We assume that scrappage rates for vehicles three years old and less would not change in response to higher prices for new vehicles. Since changes in new vehicle prices affect the number of vehicles per driver, we also calculate changes in scrappage rates for vehicles of each age due to lagged changes in vehicles per driver. Specifically, we use the estimated elasticities, by age, of scrappage with respect to lagged vehicles per driver to calculate changes in scrappage rates in each calendar year due to changes in vehicles per driver in the previous calendar year.

These overall age-specific changes in scrappage rates due to each of the scenarios are then applied to scrappage rates for vehicles of each age in the baseline projected vehicle populations for California to produce estimates of the changes in vehicle populations due to the California Program.

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Appendix D. Rebound Effect Analysis

This appendix provides information on the "rebound" effect that is relevant for determining the effects of changes in the fuel economy of the vehicle fleet on vehicle miles traveled in California. The rebound effect is measured as the effect of changes in the cost per mile of travel (e.g., fuel costs) on vehicle miles traveled; the effect is traditionally measured as an elasticity—the percentage increase in vehicle miles traveled that would results from a one percent decrease in the cost per mile of travel. The model we develop to estimate the rebound effect is based upon the general methodology and data employed by researchers at the University of California at Irvine (hereafter, "Irvine study").[27]

This appendix consists of the following three parts:

- Overview of Irvine study;
- Modifications to Irvine study data and estimation procedures; and
- Estimated Rebound Effect in California.

D.1. Overview of Irvine Study

The Irvine study develops a model that posits simultaneous determination of three variables (using three equations) related to vehicle use: fleetwide vehicle miles traveled ("VMT"); fleetwide vehicle stock (number of vehicles); and fleetwide vehicle fuel intensity (the inverse of fuel economy).[28] In the model, VMT and vehicle stock depend on lagged dependent variables, several exogenous variables, and cost per mile of travel, *pm*—defined as the price of fuel (dollars per gallon) divided by fuel economy miles per gallon).[29] The variable *pm* is endogenous because it depends on fuel economy. The VMT equation also includes the endogenous vehicle stock variable as well as interaction terms of *pm* with income, *pm* with urbanization, and *pm* with itself (i.e., pm^2).

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[27] See Small and Van Dender 2006 and 2006a and Small 2006 and 2006a.

[28] The authors use the natural logarithm of VMT per adult as one of the three endogenously determined variables. For simplicity, we refer to this variable as VMT.

The fuel intensity equation includes a lagged dependent variable, several exogenous explanatory variables, a Corporate Average Fuel Economy ("CAFE") variable, and the endogenous VMT variable. The Irvine study treats CAFE regulation as a factor that contributes to actual fuel economy rather than as a measure of observed fuel economy. Thus the intent of the CAFE variable to measure the ratio of fuel economy under CAFE to what fuel economy would have been without CAFE. The Irvine study uses fuel economy data for years prior to CAFE to predict what fuel economy would have been without CAFE in later years.

The estimated ***short-run*** national rebound effect in the Irvine study depends most importantly on the estimated elasticity of VMT with respect to the cost of travel, *pm*. The estimated *long run* national rebound effect in the Irvine study depends most importantly on the estimated short-run elasticity of VMT with respect to *pm* and the estimated coefficient of lagged VMT in the VMT equation.

D.1.1. Irvine Study Variables and Data Set

The Irvine study uses a cross-sectional time-series dataset with data on all fifty U.S. states and the District of Columbia over the years 1966 through 2001. Table D-1 provides an overview of the variables used in the Irvine study. The description of each variable explains the data used to construct it. Though the study uses a cross-sectional time-series dataset, not every variable has state-specific values (e.g., only national data were obtained on new car loan interest rates, so the variable *interest* differs over time but not across states). In addition, some variables mix national and state-specific elements. For example, income (*inc*) and the price of fuel (*pf*) come state-specific data on nominal values, but are translated into real terms with national deflators.

D.1.2. Irvine Study Estimation Procedures

The Irvine study estimates the three equations described above using several different approaches: ordinary least squares ("OLS"); two-stage least squares ("2SLS"); three-stage least squares ("3SLS"); and generalized method of moments ("GMM"). The authors conclude that the most appropriate estimator is 3SLS.

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[29] Most of the variables in the Irvine study are expressed as natural logarithms for the estimation. Following the notation used in the Irvine study, we denote these variables in lower case and we denote non-logarithmic variables in upper case.

Table D-1. Variables Used in the Irvine Study

Variable Name	Description	Detail Level
Endogenous		
vma	VMT per adult	State
vehstock	Registered vehicles per adult	State
fint	Fuel intensity (fuel use per mile)	State
Exogenous		
adrm	Adults per mile of roadway	State
Cafe	The ratio of CAFE regulated fuel efficiency to desired fuel efficiency	National
D7479	Dummy variable for years 1974 and 1979	National
inc	Per capita personal income (deflated by national CPI)	State/National
interest	National new car loan interest rate	National
licad	Licensed drivers per adult	State
pf	Price of gasoline (deflated by national CPI)	State/National
pm=pf+fint	Cost of travel	State
pm^2	Cost of travel squared	State
pm(inc-minc):*	Interaction of p_m and *inc* variable, where *minc* is the mean of *inc*	State
pm(Urban-mUrban)*	Interaction of p_m and *Urban*, where *mUrban* is the mean of *Urban*	State
popratio	Population per adult	State
pv	Index of new car prices	National
Trend, Trend66-73, Trend74-79, Trend80+	Linear time trends	National
Railpop	Fraction of state's population living in MSAs with heavy rail transit	State
Urban	Fraction of state's population living in metropolitan areas	State
Z1, . . ., Z51	Dummy variable for each state	State

Notes: Lower-case variables are in natural logarithms.
Source: Small and Van Dender (2006).

D.2. Modifications to Irvine Study Data and Estimation Procedure

We develop an estimated rebound effect in California based upon modifications to several data series as well as the primary estimation procedure of the Irvine study.

We have received all of the underlying data and programs (Small 2006a) used in most recent versions of the Irvine study (Small and Van Dender 2006 and 2006a). To develop more appropriate results for the rebound in effect in California, we have made several modifications in the data and estimation methodology developed in the Irvine study.

- *State dummy variables.* The code for the VMT equation restricted the coefficients of the dummy variables for the States of Nevada and Nebraska to be the same. We edited the estimation code so that the two states had separate coefficients.
- *Income and gasoline prices.* We adjusted the income and gasoline price data to reflect state differences in cost of living. With these data, we were able to update the estimation of the VMT equation and other equations
- *Trend variable.* We modified the *Trend* variable to provide a superior and more consistent specification. Rather than using a single *Trend* variable for the VMT and vehicle stock equations, we used three separate *Trend* variables, the first covering the years 1966 through 1973, the second covering the years 1974 through 1979, and the third covering the years 1980 through 2001.
- *Dummy variables for 1974 and 1979.* We split the joint indicator variable for 1974 and 1979 into two separate dummy variables to allow the effects of these two independent shocks to differ from one another.
- *Estimation.* We estimated the VMT equation using 2SLS (rather than 3SLS).

D.2.1. Income and Gasoline Prices

The Irvine study uses nominal state-level income data from the U.S. Bureau of Economic Analysis (“BEA”) and state population data from the U.S. Census Bureau to derive nominal income per capita estimates. For the gas price data, the authors use state-level nominal data from the U.S. Energy Information Administration (“EIA”). The authors deflated both of these data series to 1987 dollars using the national consumer price index for all urban consumers (“CPI”) from the U.S. Bureau of Labor Statistics (“BLS”). These values do not account for differences in the cost of living across states. To account for these differences, we developed state-specific cost of living indices based on city-level data from ACCRA (formerly “American Chamber of Commerce Researchers Association”) and the BLS. These indices are used to calculate real income and gas price data that reflect differences in purchasing power across states and over time.

D.2.2. Trend Variable

The Irvine study incorporates different trend variables in different equations. In the VMT and vehicle stock equations, the Irvine study uses a linear time trend (*Trend*). In the fuel economy equation, the Irvine study uses three separate linear trends—one for the period from 1966 to 1973 (*Trend66-73*) to cover the years before the OPEC embargo in 1974, one from 1974 to 1979 (*Trend74-79*) to cover the years between the OPEC embargo and the Iranian revolution in 1979, and one from 1980 to 2001 (*Trend80+*) to cover the period after the Iranian revolution. To test for the possibility that driving behavior was also affected differently in these three periods, we performed a Wald test for the inclusion of *Trend66-73* and *Trend74-79* in addition to *Trend*. (This specification is econometrically equivalent to including the three trends from the fuel economy equation since *Trend80+* is constructed as a linear combination of the other trend variables.) The Wald test produced evidence that a nonlinear three-part trend in the VMT equation is superior to the simple linear trend used by the authors. Another Wald test produced similar evidence for the vehicle stock equation. So we modified the trend variable in the VMT and vehicle stock equations to correspond to the three-period trend variable used by the authors in their fuel economy equation.

D.2.3. Dummy Variables for 1974 and 1979

The Irvine study provides a single dummy variable in the VMT and fuel economy equations for 1974 and 1979 (*D7479*) to "represent gasoline supply disruptions in 1974 and 1979," presumably referring to the 1974 oil embargo and the 1979 Iranian revolution. We used two separate dummy variables to allow the effects of these two "shock years" to differ from one another. There is no *a priori* reason to expect that the effects of these two events were identical. A Wald test produced evidence that separating the two effects provides a superior specification.

D.2.4. Estimation

We used 2SLS to estimate the VMT equation because it is a non-system estimator that prevents specification errors in one equation from affecting parameter estimates for other equations. We concluded that 3SLS was less appropriate for this model, due to concerns about the data used to construct some variables, and, in particular, concerns about the construction of the CAFE variable.

D.3. Estimated Rebound Effect in California

Table D-2 shows the results of our estimation of the VMT equation. Because the estimated coefficient of the interaction term of *pm* with *income* (i.e., *pm**(*inc-minc*)) was statistically insignificant, we excluded that variable from our final estimation of the VMT equation. The estimated coefficient on *pm* in the VMT equation gives the short-run national rebound effect at the sample mean of the dataset used in the analysis. The long-run effect is a function of the coefficient on lagged VMT.

Table D-2. Estimation of the VMT Equation

Variables	**Coefficients from 2SLS Estimation**	
pm=pf+fint	-0.0497	(-8.41)
pm^2	-0.0280	(-3.32)
pm(inc-minc):*		
pm(Urban-mUrban)*	0.0523	(3.95)
$vma_{(t-1)}$	0.7933	(53.79)
Sample Average Rebound Effect		
Short-Run		4.97%
Long-Run		24.03%

Notes: t-statistics in parenthesis; rebound effects calculated using only coefficients from the VMT equation.

By substituting California-specific values for *Urban* and *pm* and using the estimated coefficients on the interaction terms, we develop rebound effect estimates for California at the sample mean of the California dataset used in the analysis. Table D-3 shows these estimates.

Table D-3. California Short- and Long-Run Rebound Effects

Rebound Effect	
Short-Run	2.76%
Long-Run	13.36%

We use the estimated short- and long- run rebound effects in California to estimate the effects of changes in vehicle fleet fuel economy in each year under the scenarios analyzed in this report. We estimate changes in vehicle miles traveled by vehicle class (PC, LDT1, and LDT2+). The change in fleetwide fuel economy in a given year is a function of the change in new vehicle fuel economy in that year as well as the changes in new vehicle fuel economy in previous years. The change in VMT in a given year is a function of the change in fleetwide fuel economy in that year as well as the change in VMT in previous years.

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Appendix E. EMFAC2007 Pollutant Emissions Modeling

This appendix describes the development and use in this study of the EMFAC2007 Fleet Emissions Model, an Excel spreadsheet model used by CARB in analyses of emissions effects in California. This study uses the November 1, 2006, version of EMFAC2007 to generate estimates of the impacts of the California Program on criteria pollutants in California.[30] The model accounts for the impact of the "fleet-turnover" effect and "rebound" effect on emissions of VOC, NOx, CO, SOx, PM10, and five air toxics. The discussion below summarizes the methodology used to develop model-year specific grams-per-mile (g/mi) emission factors, vehicle populations, and vehicle miles traveled ("VMT"), and how those parameters were adjusted to account for the emissions impacts of the various scenarios investigated in this study.

E.1. Baseline Model-Year Specific Emissions, Population, and VMT

The baseline model-year-specific emission rates, vehicle populations, and VMT were generated by running EMFAC2007 for each individual model year included in EMFAC2007 for the calendar year being evaluated. For example, a calendar year 2020 EMFAC2007 run includes vehicles from the 1976 model year through the 2020 model year (45 model years total). The model output consists of ton-per-day emissions results, which are divided by the estimated daily VMT by vehicles of that model year to arrive at g/mi emission rates for each model year. The model runs were configured to output summer-average emissions and also emissions, both at the statewide level and specifically for the South Coast Air Basin ("SCAB"), and estimates were prepared separately for the passenger car (PC), light-duty truck 1 (LDT1), light-duty truck 2 (LDT2), and medium-duty vehicle (MDV) classes (which cover all light-duty vehicles through 8,500 lbs. gross vehicle weight rating).

The VOC (exhaust and evaporative emissions combined) and NOx emission rates developed in this manner are illustrated in Figure E-1 for passenger cars. Of particular interest in this figure is the relatively high g/mi emissions for the older model year vehicles relative to the newer vehicles, which holds true for both pollutants. For this reason, relatively small shifts in the age

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[30] The EMFAC2007 model can be downloaded from CARB's internet website at http://www.arb.ca.gov/msei/on-road/latest_version.htm. Note that the executable version of the model used by AIR was recompiled from the Fortran code to allow reporting of the ton-per-day emissions estimates to four digits past the decimal point rather than two. This is necessary when calculating gram-per-mile emission rates for some vehicle classes and model years that have a relatively small population.

distribution of vehicles in the fleet can result in a significant increase in the fleet average emission factor. Such shifts in the age distribution are the result of the “Fleet Turnover” effect.

The model year specific g/mi emission rates developed as described above were used in conjunction with vehicle populations and daily VMT by vehicle age to generate ton-per-day (tpd) emissions estimates. Emission inventory estimates for the state were generated by multiplying the vehicle population (by model year) by the per-vehicle average daily VMT (by model year) and the g/mi emission rate (by model year). These products were then summed over all model year vehicles in the fleet (e.g., 1976 through 2020 for a calendar year 2020 analysis) to obtain the inventory for the scenario being analyzed. A sample of the calculation for baseline exhaust VOC emissions from passenger cars is shown in Figure E-1, and a comparison of the results directly from EMFAC2007 versus those obtained with the emissions model developed for this effort is shown below.

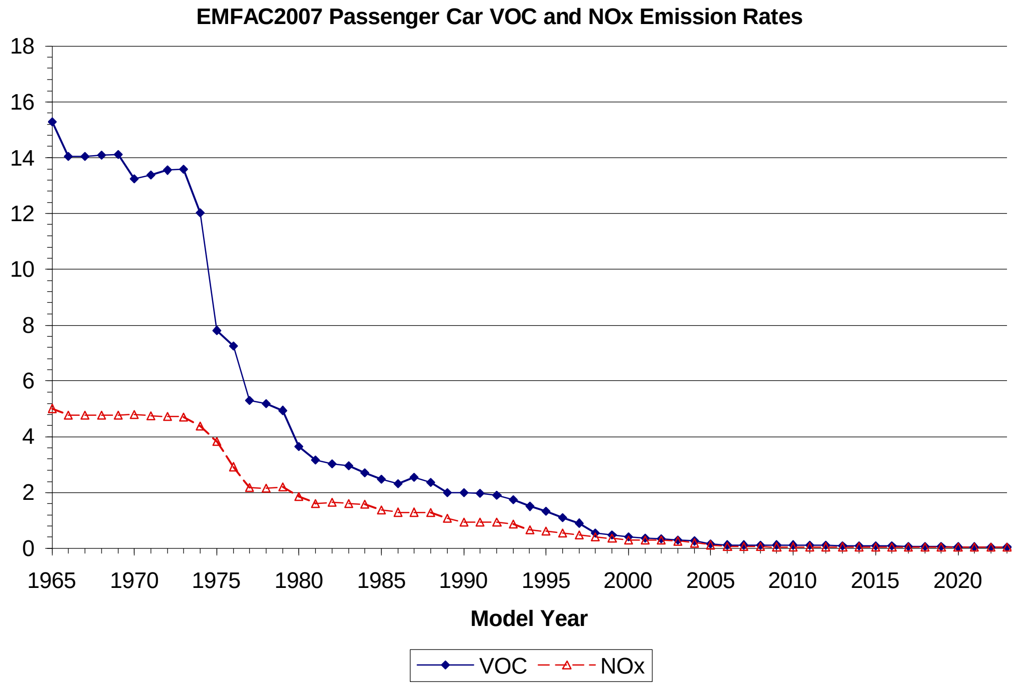

Figure E-1. EMFAC2007 Passenger Car VOC and NOx Emission Rates (VOC Includes Evaporative Emissions)

PC Exhaust VOC Directly from EMFAC2007: 31.90 tpd

PC Exhaust VOC from Fleet Emissions Model: 31.90 tpd

PC NOx Directly from EMFAC2007: 63.28 tpd

PC NOx from Fleet Emissions Model: 63.28 tpd

As observed above, the Fleet Emissions Model agrees exactly with the EMFAC2007 emission model for both VOC and NOx.

Table E-1. Summary of 2020 Statewide Passenger Car Exhaust VOC Inventory Calculation

Model Year	Total Passenger Cars	Daily VMT (mi/day)	Exhaust VOC (g/mi)	Exhaust VOC (tpd)
2020	996,373	55.8	0.011	0.67
2019	984,117	48.3	0.013	0.66
2018	942,424	43.9	0.014	0.63
2017	911,735	40.8	0.015	0.62
2016	882,463	38.4	0.017	0.65
2015	886,284	36.4	0.019	0.68
2014	852,640	34.8	0.020	0.66
2013	827,749	33.3	0.021	0.65
2012	785,071	32.0	0.023	0.62
2011	740,260	30.9	0.024	0.59
2010	700,575	29.9	0.026	0.59
2009	655,833	28.9	0.028	0.58
2008	613,086	28.0	0.028	0.53
2007	569,920	27.2	0.031	0.54
2006	530,455	26.5	0.035	0.54
2005	502,630	25.8	0.051	0.73
2004	416,920	25.1	0.088	1.02
2003	390,251	24.5	0.105	1.11
2002	333,449	24.0	0.115	1.01
2001	305,670	23.4	0.124	0.98
2000	280,392	22.9	0.140	0.99
1999	204,643	22.4	0.208	1.05
1998	172,099	21.9	0.279	1.16
1997	147,974	21.4	0.301	1.05
1996	115,108	21.0	0.326	0.87
1995	122,526	20.6	0.375	1.04
1994	100,700	20.2	0.441	0.99
1993	90,423	19.8	0.627	1.24
1992	80,816	19.4	0.731	1.26
1991	89,396	19.0	0.741	1.39
1990	84,727	18.7	0.711	1.24

1989	79,655	18.4	0.676	1.09
1988	67,569	18.0	0.638	0.86
1987	60,002	17.7	0.632	0.74
1986	46,731	17.4	0.636	0.57
1985	36,213	17.1	0.678	0.46
1984	26,612	16.8	0.810	0.40
1983	15,311	16.6	0.915	0.26
1982	10,327	16.2	0.946	0.17
1981	7,956	16.0	0.913	0.13
1980	6,181	15.7	1.227	0.13
1979	8,140	15.4	1.957	0.27
1978	6,318	15.2	1.963	0.21
1977	4,410	14.9	2.003	0.15
1976	3,208	14.7	2.563	0.13
			Total Exhaust VOC:	**31.90**

E.2. Scenarios

As discussed elsewhere in this report, emission inventories for the state of California and for the SCAB are estimated for two scenarios:

1. Federal Tier 2 Program (baseline); and
2. California Program (including exhaust and evaporative emission standards, ZEV Standards, and GHG Standards).

Inventories for the two cases are estimated by generating by-model-year emission factors using EMFAC2007, and multiplying these by populations and vehicle miles traveled per day. For the Federal Program, there are no population or VMT adjustments, but for the California Program, which includes both the ZEV Standards and the GHG Standards, there are adjustments to populations and vehicle miles traveled, since both cases will result in increased costs and reduced new vehicle purchases relative to the Federal Program. Also, there are additional adjustments to vehicle miles traveled for newer vehicles due to rebound effects.

E.3. Emission Rates by Vehicle Class and Model Year

Emission factors for the Federal Program are generated using EMFAC2007 and modifying the EMFAC Tech Groups in 2009 and later model years to match EPA's predicted Tier 2 Bin percentages. The Tier 2 2009+ mix for MOBILE6.2 is shown in Table E-3. Also shown in Table E-3 are the EMFAC Technology Groups that are the same as these bins.

Table E-2. MOBILE6.2 Tier 2 2009 Mix.

Bin	EMFAC Tech Grp	LDV/T1	LDT2	LDT3	LDT4	Total
8	35	0.0%	0.0%	26.0%	100.0%	7.5%
7	N/A	0.0%	30.0%	0.0%	0.0%	10.3%
6	N/A	0.0%	30.0%	0.0%	0.0%	10.3%
5	28	10.0%	20.0%	74.0%	0.0%	19.5%
4	33	10.0%	20.0%	0.0%	0.0%	11.9%
3	32	55.0%	0.0%	0.0%	0.0%	27.9%
2	30	25.0%	0.0%	0.0%	0.0%	12.7%
Total		100%	100%	100%	100%	100%
NOx Avg		0.033	0.097	0.104	0.200	0.070
NMOG Avg		0.049	0.086	0.099	0.125	0.070

N/A= not available

As noted in Table E-3, there are Tech groups for Bins 6 and 7, which are used only for LDT2s in EMFAC. Instead of creating new Technology Groups in EMFAC, the analysis used percentages of vehicles in Bins 4, 5, and 8 to simulate the Tier 2 percentages. This results in the same NMOG, but slightly higher fleet-weighted NOx, as shown in Table E-4. Thus, the EMFAC analysis for Tier 2 has slightly less benefit than it should, which is a conservative assumption for this anlysis.

Also, LDT3s and LDT4s must be combined into a single EMFAC Medium Duty Vehicle ("MDV") category. This analysis assumed 68% of MDVs are LDT3s, and 32% are LDT4s, which is consistent with MOBILE6.2. For Tier 2 evaporative emissions, the 2009+ model year Technology group assignments are 100% Technology Group 15 for passenger cars, and 100% Technology Group 35 for LDT1s, LDT2s, and MDVs. These technology groups correspond to the LEVII Near Zero evaporative standards for these vehicle classes.

Table E-3. 2009+ Mix Used in EMFAC2007 to Model Tier 2

Bin	EMFAC Tech Grp	LDV/T1	LDT2	LDT3	LDT4	Total
8	35	0.0%	25.4%	26.0%	100.0%	16.1%
7	N/A	0.0%	0.0%	0.0%	0.0%	0.0%
6	N/A	0.0%	0.0%	0.0%	0.0%	0.0%
5	28	10.0%	54.6%	74.0%	0.0%	31.3%
4	33	10.0%	20.0%	0.0%	0.0%	11.9%
3	32	55.0%	0.0%	0.0%	0.0%	27.9%
2	30	25.0%	0.0%	0.0%	0.0%	12.7%
Total		100%	100%	100%	100.0%	100%
NOx Avg		0.033	0.097	0.104	0.200	0.070
NMOG Avg		0.049	0.095	0.099	0.125	0.073

N/A = not available

For the California Program, the emissions analysis relies on estimates of the percentages of ZEVs, PZEVs, and AT-PZEVs that would be sold by manufacturers, based on the regulatory requirements and compliance plans described elsewhere in this report. Then, the percent of LEVIIs and ULEVIIs are selected in order to meet ARB's NMOG requirements. These new technology fractions are input into EMFAC2007, and the model is re-run for both the state and for the SCAB to produce emissions by model year and vehicle class. The technology fractions for the California program are shown in Table E-4.

Table E-4. Technology Fractions Used for Modeling the California Program.

	Technology Groups for Modeling the California Program						
Tech Grp	**28**	**29**	**31**	**37**	**25**	**32**	**33**
NMOG	**0.075**	**0.04**	**0.0085**	**0.0085**	**0**	**0.04**	**0.04**
Model Yr	**LEV II**	**ULEV II**	**PZEV**	**AT PZEV**	**ZEV**	**Bin3**	**Bin 4**
				PCs			
2009	0.091	0.050	0.365	0.103	0.001	0.290	0.100
2010	0.000	0.135	0.408	0.112	0.001	0.244	0.100
2011	0.081	0.050	0.449	0.121	0.001	0.198	0.100
2012	0.171	0.000	0.487	0.138	0.004	0.100	0.100
2013	0.161	0.000	0.494	0.140	0.005	0.100	0.100

2014	0.148	0.000	0.501	0.142	0.009	0.100	0.100
2015	0.197	0.000	0.493	0.193	0.017	0.000	0.100
2016	0.186	0.000	0.500	0.196	0.018	0.000	0.100
2017	0.185	0.000	0.500	0.196	0.019	0.000	0.100
2018	0.212	0.000	0.481	0.173	0.034	0.000	0.100
2019	0.172	0.000	0.481	0.173	0.034	0.040	0.100
2020	0.172	0.000	0.481	0.173	0.034	0.040	0.100
2021	0.160	0.000	0.462	0.165	0.033	0.080	0.100
2022	0.160	0.000	0.462	0.165	0.033	0.080	0.100
2023	0.159	0.000	0.463	0.165	0.033	0.080	0.100
				LDT1s			
2009	0.171	0.000	0.377	0.062	0.000	0.290	0.100
2010	0.165	0.000	0.422	0.069	0.000	0.244	0.100
2011	0.157	0.000	0.468	0.077	0.000	0.198	0.100
2012	0.153	0.000	0.511	0.094	0.000	0.142	0.100
2013	0.144	0.000	0.519	0.095	0.000	0.142	0.100
2014	0.177	0.000	0.527	0.096	0.000	0.100	0.100
2015	0.228	0.000	0.523	0.149	0.000	0.000	0.100
2016	0.219	0.000	0.530	0.151	0.000	0.000	0.100
2017	0.219	0.000	0.530	0.151	0.000	0.000	0.100
2018	0.249	0.000	0.521	0.130	0.000	0.000	0.100
2019	0.208	0.000	0.522	0.130	0.000	0.040	0.100
2020	0.208	0.000	0.522	0.130	0.000	0.040	0.100
2021	0.194	0.000	0.504	0.122	0.000	0.080	0.100
2022	0.194	0.000	0.504	0.122	0.000	0.080	0.100
2023	0.193	0.000	0.505	0.122	0.000	0.080	0.100
				LDT2s			
2009	0.7100	0.0000	0.0710	0.0190	0.0000	0.0000	0.2000
2010	0.6960	0.0000	0.0820	0.0220	0.0000	0.0000	0.2000
2011	0.6840	0.0000	0.0920	0.0240	0.0000	0.0000	0.2000
2012	0.6690	0.0000	0.1020	0.0290	0.0000	0.0000	0.2000
2013	0.6680	0.0000	0.1030	0.0290	0.0000	0.0000	0.2000
2014	0.6650	0.0000	0.1050	0.0300	0.0000	0.0000	0.2000
2015	0.6590	0.0000	0.1010	0.0400	0.0000	0.0000	0.2000
2016	0.6560	0.0000	0.1030	0.0410	0.0000	0.0000	0.2000

2017	0.6560	0.0000	0.1030	0.0410	0.0000	0.0000	0.2000
2018	0.6630	0.0000	0.1000	0.0370	0.0000	0.0000	0.2000
2019	0.6630	0.0000	0.1000	0.0370	0.0000	0.0000	0.2000
2020	0.6630	0.0000	0.1000	0.0370	0.0000	0.0000	0.2000
2021	0.6690	0.0000	0.0960	0.0350	0.0000	0.0000	0.2000
2022	0.6690	0.0000	0.0960	0.0350	0.0000	0.0000	0.2000
2023	0.6690	0.0000	0.0960	0.0350	0.0000	0.0000	0.2000
MDVs							
2009	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2010	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2011	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2012	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2013	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2014	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2015	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2016	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2017	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2018	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2019	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2020	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2021	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2022	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
2023	1.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

E.3.1. Toxics Estimates

Unlike MOBILE6, the EMFAC2007 model does not include estimates of the toxic species benzene, 1,3 butadiene, acrolein, formaldehyde, and acetaldehyde. To obtain toxics emissions from the EMFAC2007, the following process was used. First, the MOBILE6-MSAT model was modified to output the air toxics fractions (i.e., the ratio of the particular toxic emissions to VOC emissions) by vehicle class and model year. The model was run from 2003-2023, using the flat limits for California summer fuel parameters. While these limits are somewhat higher than the actual values for in-use gasoline, the in-use properties vary somewhat from year-to-year, and the use of the flat limits instead of in-use properties is not expected to have a significant effect on the toxic ratios for this analysis. Next, the fractions were averaged by age and vehicle class. The final exhaust toxics fractions, which are multiplied by the exhaust VOC emissions from each class, are shown in Table E-5.

Table E-5 Exhaust Toxics Fractions Used to Estimate Toxics for EMFAC2007 (Obtained from MOBILE6-MSAT)

Exhaust Air Toxics Fractions

	Benzene			1,3 Butadiene			Formaldehyde			Acetaldehyde			Acrolein		
Age	**PC**	**LDT1/2**	**MDV**	**PC**	**LDT1/2**	**MDV**	**PC**	**LDT1/2**	**MDV**	**PC**	**LDT1/2**	**MDV**	**PC**	**LDT1/2**	**MDV**
1	0.06414	0.06424	0.06424	0.00494	0.00486	0.00486	0.01396	0.01414	0.01414	0.00817	0.00793	0.00793	0.00060	0.00060	0.00060
2	0.06414	0.06424	0.06424	0.00494	0.00486	0.00486	0.01396	0.01414	0.01414	0.00817	0.00793	0.00793	0.00060	0.00060	0.00060
3	0.06412	0.06419	0.06400	0.00495	0.00488	0.00492	0.01395	0.01413	0.01407	0.00817	0.00793	0.00792	0.00060	0.00060	0.00060
4	0.06392	0.06392	0.06372	0.00499	0.00493	0.00498	0.01389	0.01404	0.01398	0.00815	0.00792	0.00791	0.00060	0.00060	0.00060
5	0.06372	0.06367	0.06344	0.00503	0.00499	0.00504	0.01383	0.01397	0.01389	0.00814	0.00791	0.00790	0.00060	0.00060	0.00060
6	0.06354	0.06340	0.06315	0.00506	0.00505	0.00510	0.01378	0.01388	0.01381	0.00813	0.00790	0.00788	0.00060	0.00060	0.00060
7	0.06335	0.06314	0.06288	0.00510	0.00510	0.00516	0.01372	0.01380	0.01372	0.00811	0.00789	0.00787	0.00060	0.00060	0.00060
8	0.06316	0.06289	0.06263	0.00514	0.00516	0.00521	0.01366	0.01373	0.01364	0.00810	0.00788	0.00786	0.00060	0.00060	0.00060
9	0.06297	0.06265	0.06240	0.00518	0.00521	0.00526	0.01360	0.01365	0.01357	0.00808	0.00787	0.00785	0.00060	0.00060	0.00060
10	0.06276	0.06244	0.06219	0.00522	0.00525	0.00531	0.01355	0.01359	0.01351	0.00807	0.00786	0.00784	0.00060	0.00060	0.00060
11	0.06255	0.06223	0.06198	0.00526	0.00530	0.00535	0.01349	0.01353	0.01345	0.00805	0.00785	0.00783	0.00060	0.00060	0.00060
12	0.06232	0.06201	0.06176	0.00530	0.00533	0.00539	0.01343	0.01348	0.01340	0.00804	0.00784	0.00783	0.00060	0.00060	0.00060
13	0.06210	0.06182	0.06157	0.00534	0.00537	0.00542	0.01337	0.01343	0.01335	0.00802	0.00784	0.00782	0.00060	0.00060	0.00060
14	0.06187	0.06160	0.06135	0.00538	0.00540	0.00545	0.01331	0.01339	0.01331	0.00801	0.00783	0.00781	0.00060	0.00060	0.00060
15	0.06169	0.06140	0.06113	0.00542	0.00543	0.00548	0.01326	0.01336	0.01328	0.00800	0.00782	0.00781	0.00060	0.00060	0.00060
16	0.06151	0.06120	0.06093	0.00546	0.00546	0.00552	0.01321	0.01333	0.01324	0.00798	0.00782	0.00781	0.00060	0.00060	0.00060
17	0.06122	0.06084	0.06054	0.00552	0.00552	0.00558	0.01312	0.01325	0.01315	0.00796	0.00781	0.00779	0.00060	0.00060	0.00060
18	0.06093	0.05999	0.05966	0.00558	0.00553	0.00560	0.01304	0.01327	0.01316	0.00794	0.00784	0.00783	0.00060	0.00060	0.00060
19	0.06059	0.05903	0.05869	0.00565	0.00553	0.00560	0.01294	0.01331	0.01320	0.00792	0.00789	0.00787	0.00060	0.00060	0.00060
20	0.06022	0.05798	0.05761	0.00572	0.00552	0.00560	0.01283	0.01338	0.01326	0.00789	0.00795	0.00792	0.00060	0.00060	0.00060
21	0.05972	0.05684	0.05645	0.00579	0.00550	0.00558	0.01274	0.01348	0.01335	0.00788	0.00801	0.00799	0.00060	0.00060	0.00060
22	0.05915	0.05560	0.05520	0.00586	0.00547	0.00555	0.01265	0.01360	0.01347	0.00786	0.00809	0.00806	0.00060	0.00060	0.00060
23	0.05842	0.05431	0.05389	0.00601	0.00543	0.00552	0.01260	0.01375	0.01361	0.00786	0.00817	0.00815	0.00060	0.00060	0.00060
24	0.05714	0.05300	0.05257	0.00597	0.00542	0.00546	0.01275	0.01395	0.01376	0.00794	0.00826	0.00823	0.00060	0.00060	0.00060
25	0.05581	0.05170	0.05128	0.00594	0.00541	0.00541	0.01293	0.01415	0.01393	0.00801	0.00834	0.00832	0.00060	0.00060	0.00060
26	0.05581	0.05170	0.05128	0.00594	0.00541	0.00541	0.01293	0.01415	0.01393	0.00801	0.00834	0.00832	0.00060	0.00060	0.00060
27	0.05581	0.05170	0.05128	0.00594	0.00541	0.00541	0.01293	0.01415	0.01393	0.00801	0.00834	0.00832	0.00060	0.00060	0.00060
28	0.05581	0.05170	0.05128	0.00594	0.00541	0.00541	0.01293	0.01415	0.01393	0.00801	0.00834	0.00832	0.00060	0.00060	0.00060
29	0.05581	0.05170	0.05128	0.00594	0.00541	0.00541	0.01293	0.01415	0.01393	0.00801	0.00834	0.00832	0.00060	0.00060	0.00060
30	0.05581	0.05170	0.05128	0.00594	0.00541	0.00541	0.01293	0.01415	0.01393	0.00801	0.00834	0.00832	0.00060	0.00060	0.00060
31	0.05581	0.05170	0.05128	0.00594	0.00541	0.00541	0.01293	0.01415	0.01393	0.00801	0.00834	0.00832	0.00060	0.00060	0.00060
32	0.05581	0.05170	0.05128	0.00594	0.00541	0.00541	0.01293	0.01415	0.01393	0.00801	0.00834	0.00832	0.00060	0.00060	0.00060
33	0.05581	0.05170	0.05128	0.00594	0.00541	0.00541	0.01293	0.01415	0.01393	0.00801	0.00834	0.00832	0.00060	0.00060	0.00060
34	0.05581	0.05170	0.05128	0.00594	0.00541	0.00541	0.01293	0.01415	0.01393	0.00801	0.00834	0.00832	0.00060	0.00060	0.00060
35	0.05581	0.05170	0.05128	0.00594	0.00541	0.00541	0.01293	0.01415	0.01393	0.00801	0.00834	0.00832	0.00060	0.00060	0.00060
36	0.05581	0.05170	0.05128	0.00594	0.00541	0.00541	0.01293	0.01415	0.01393	0.00801	0.00834	0.00832	0.00060	0.00060	0.00060
37	0.05581	0.05170	0.05128	0.00594	0.00541	0.00541	0.01293	0.01415	0.01393	0.00801	0.00834	0.00832	0.00060	0.00060	0.00060
38	0.05581	0.05170	0.05128	0.00594	0.00541	0.00541	0.01293	0.01415	0.01393	0.00801	0.00834	0.00832	0.00060	0.00060	0.00060
39	0.05581	0.05170	0.05128	0.00594	0.00541	0.00541	0.01293	0.01415	0.01393	0.00801	0.00834	0.00832	0.00060	0.00060	0.00060
40	0.05581	0.05170	0.05128	0.00594	0.00541	0.00541	0.01293	0.01415	0.01393	0.00801	0.00834	0.00832	0.00060	0.00060	0.00060
41	0.05581	0.05170	0.05128	0.00594	0.00541	0.00541	0.01293	0.01415	0.01393	0.00801	0.00834	0.00832	0.00060	0.00060	0.00060
42	0.05581	0.05170	0.05128	0.00594	0.00541	0.00541	0.01293	0.01415	0.01393	0.00801	0.00834	0.00832	0.00060	0.00060	0.00060
43	0.05581	0.05170	0.05128	0.00594	0.00541	0.00541	0.01293	0.01415	0.01393	0.00801	0.00834	0.00832	0.00060	0.00060	0.00060
44	0.05581	0.05170	0.05128	0.00594	0.00541	0.00541	0.01293	0.01415	0.01393	0.00801	0.00834	0.00832	0.00060	0.00060	0.00060
45	0.05581	0.05170	0.05128	0.00594	0.00541	0.00541	0.01293	0.01415	0.01393	0.00801	0.00834	0.00832	0.00060	0.00060	0.00060

For evaporative toxics (benzene), the following MOBILE6 fractions were used for all ages and vehicle classes:

Hot Soak Emission Fraction: 0.00675

Diurnal Emission Fraction: 0.00610

Running Loss Emission Fraction: 0.00675

Resting Loss Emission Fraction: 0.00610

E.4. Impacts of the California Program

There are two primary effects from implementing the California program that impact criteria pollutant emissions: fleet-turnover effects and rebound effects. These are discussed below.

E.4.1. Fleet-Turnover Effects

As noted elsewhere in this report, the new vehicle price increases as a result of the ZEV and GHG Standards will have a significant impact on fleet turnover, causing reduced new vehicle sales and the retention of older, higher-emitting vehicles. This can have a substantial impact on the criteria pollutant emissions inventory, as older vehicles in the fleet can have emission rates that are a hundred times higher than those of new vehicles (see Figure E-1). Obviously, any increase in travel from these vehicles has a negative impact on the emissions inventory and air quality.

An example of the change in the distribution of vehicles in the fleet as a result of the California Program is shown in Figure E-2. This figure illustrates the change in the statewide vehicle

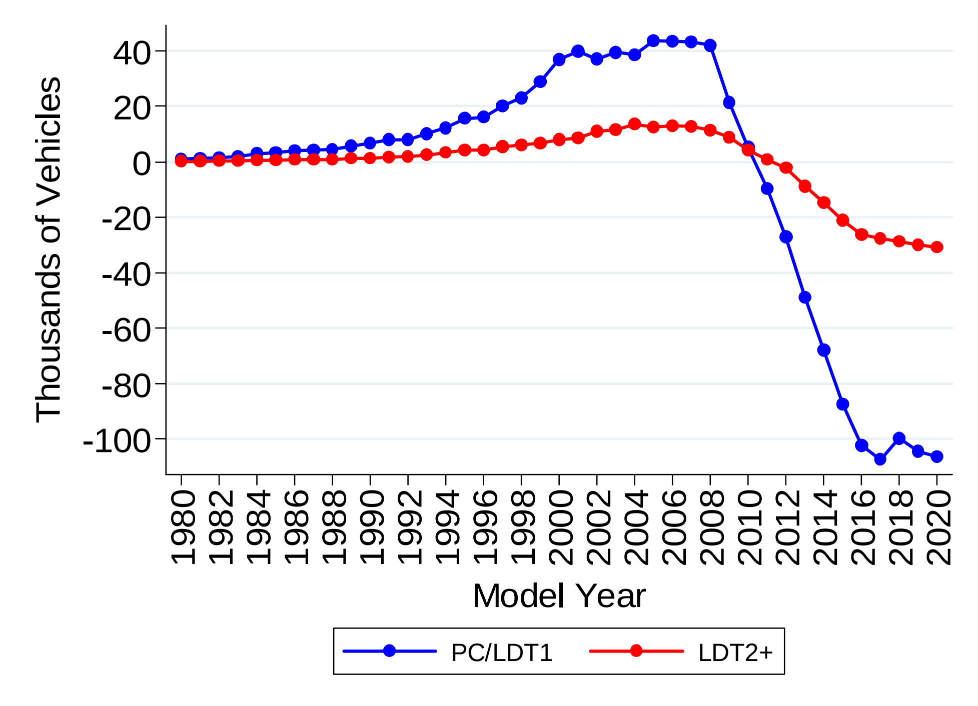

Figure E-2. Example of the Change in Statewide 2020 Vehicle Population Estimates as a Result of the Combined California Program

population in 2020, where a positive number reflects more vehicles than in the baseline case and a negative number reflects fewer vehicles than in the baseline case. As observed in the figure, the population of pre-2011 model year vehicles is increased and the population of 2011 and newer model year vehicles has decreased relative to the base case. This change in vehicle population, which results in an older vehicle fleet, also results in increased VOC, CO, NO_x, $PM_{2.5}$, and toxics emissions compared to the baseline fleet.

E.4.2. Rebound Effects

Also as noted elsewhere in this report, a secondary outcome of the improved fuel economy required by both the ZEV and GHG Standards is additional VMT being accumulated by those vehicles subject to the regulations, due to their increased fuel economy (i.e., the "rebound effect"). In general, as the cost of travel decreases, total VMT increases. An example of this effect is illustrated in Figure E-3, which shows that VMT accrual is estimated to increase from the 2009 model year (the first year of the regulation) to the 2016 model year (when the regulation is fully phased in).

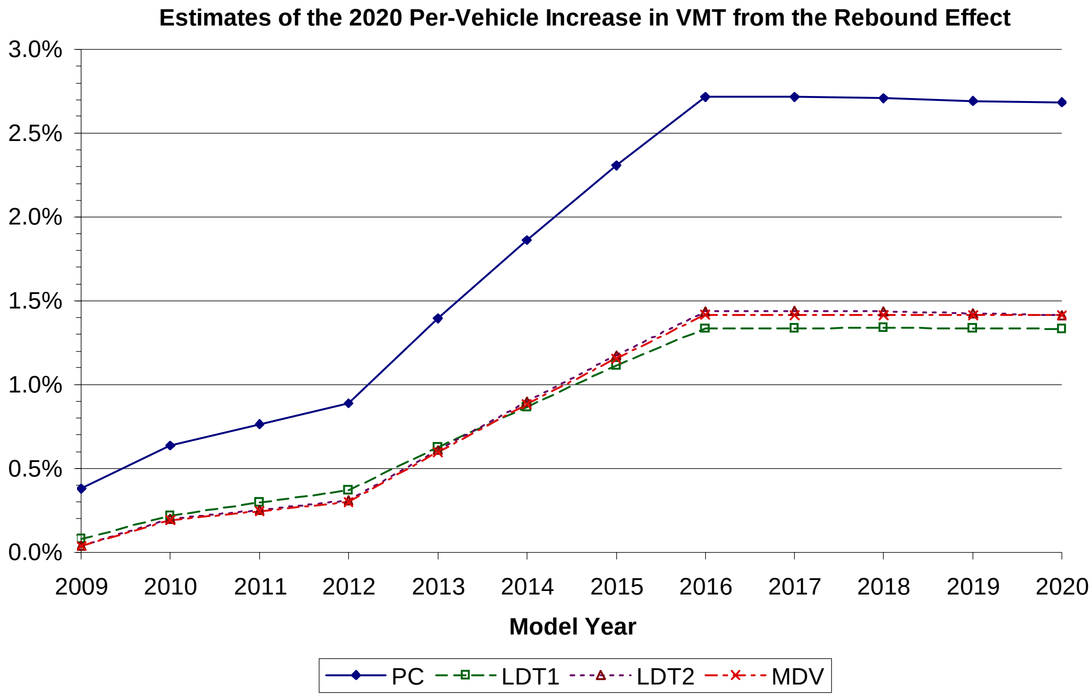

Figure E-3. Estimates of the Per-Vehicle Increase in VMT from the Rebound Effect.

E.4.3. Emissions Impacts of Fleet-Turnover and Rebound Effects

The emissions impacts of the fleet-turnover and rebound effects were calculated by modifying the baseline vehicle population estimates and the baseline per-vehicle VMT estimates in the spreadsheet model developed for this effort. Fleet turnover impacts all model year vehicles, while the rebound effect is only applied to vehicles subject to the regulation (i.e., 2009 and newer model years).

The revised population files for each of the scenarios outlined above were input into the EMFAC2007 Fleet Emissions Model developed for this study. For each scenario, the total VMT (absent rebound effects) was held constant. This was accomplished by making slight modifications to the baseline daily VMT per vehicle for all vehicles. This was necessary because the total vehicle population (and the age distribution) changed under each scenario; thus, if the baseline VMT per vehicle was applied to each model year, the total VMT under the control cases would not be equal to the total VMT under the baseline case. Once this initial VMT adjustment was made, the VMT from 2009 and newer vehicles was increased to account for the rebound effect. This second adjustment results in higher total VMT for each vehicle class.

E.5. Results

Here we present results of the EMFAC 2007 emissions modeling, both for the entire state of California and specifically for the South Coast Air Basin.[31]

E.5.1. Statewide Results

The following are statewide plots of the *difference* in emissions under the California Program relative to emissions under the Federal Program, for the summer season, in tons per day, for all vehicles under 8500 lbs GVW. Thus, *positive* values indicate that the inventories under the California Program are *higher* than under the Federal Program, while *negative* values indicate that the inventories under the California Program are *lower* than under the Federal Program. Put another way, a value of zero in any of the following charts indicates that emissions are identical under the two programs, a positive value indicates emissions are higher under the California Program than under the Federal Program, and a negative value indicates that emissions are lower under the California Program than under the Federal Program. The following charts are shown:

- VOC+NOx (Figure E-4);
- NO_x (Figure E-5);
- VOC (Figure E-6);
- CO (Figure E-7);
- Exhaust $PM_{2.5}$ (Figure F-8);
- 5 Toxics Summed (Figure E-9); and,
- SO_x (Figure E-10).

The VOC+ NOx, VOC, NOx, CO, and PM2.5 charts have been adjusted for fuel cycle effects consistent with the discussion in Appendix G. The toxics and SOx charts have not been adjusted for fuel cycle effects.

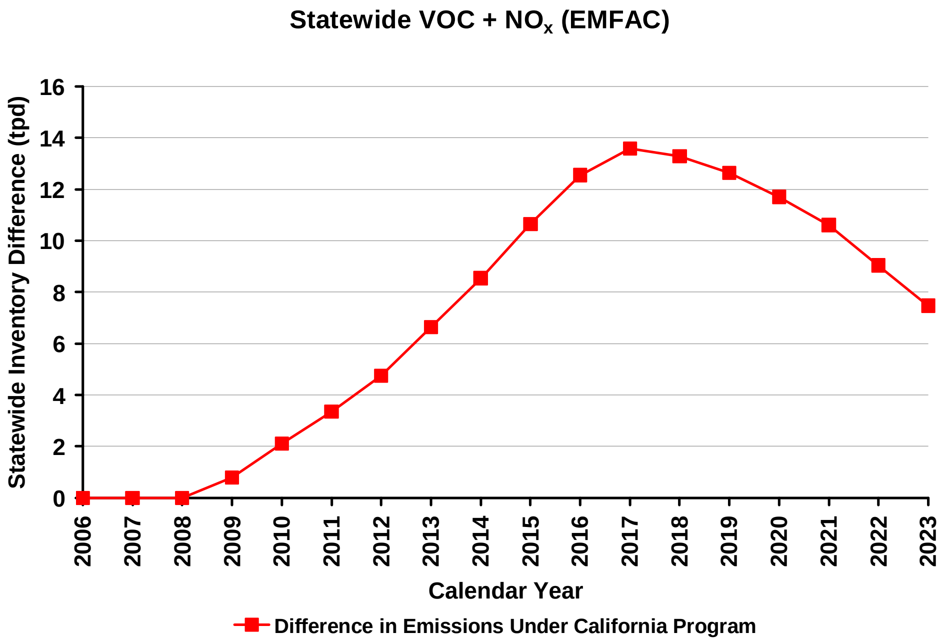

Figure E-4. Difference in Statewide emissions of VOC + NO_x under combined California Program (relative to emissions under Federal Program).

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[31] All results shown in this section, except results for SO_x and 5 Toxics Summed, include fuel cycle effects.

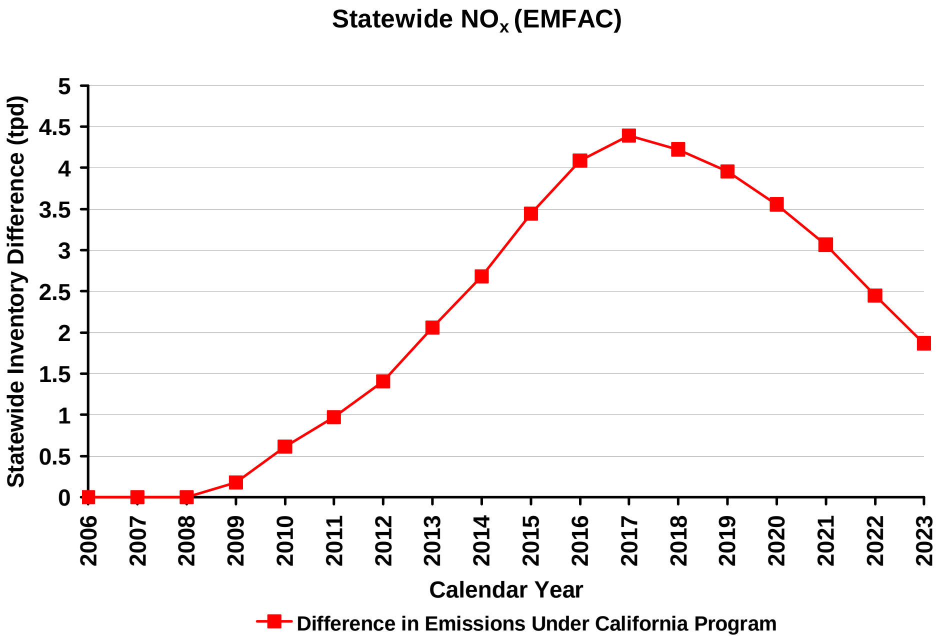

Figure E-5. Difference in statewide emissions of NO_x under combined California Program (relative to emissions under Federal Program).

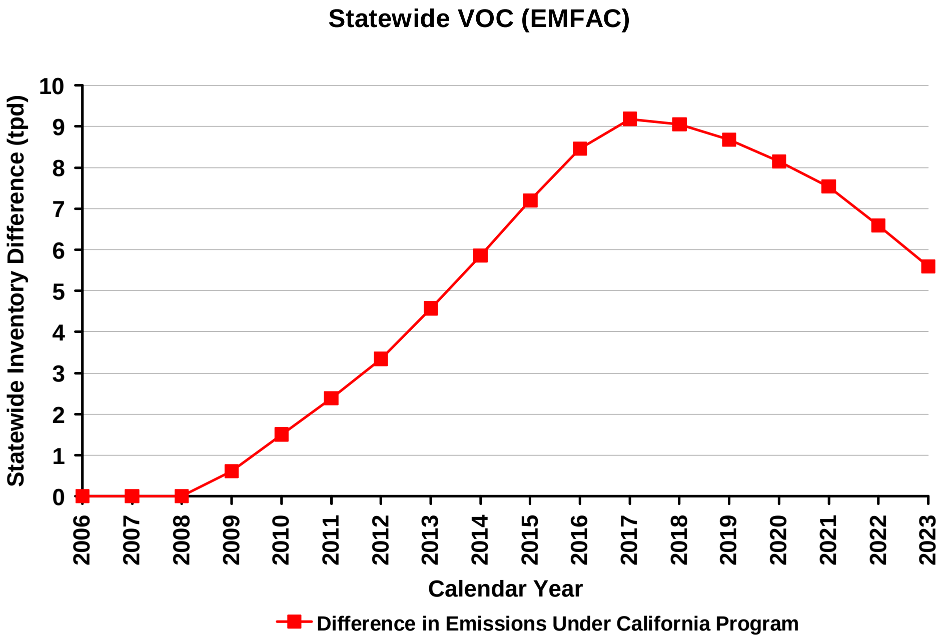

Figure E-6. Difference in statewide emissions of VOC under combined California Program (relative to emissions under Federal Program).

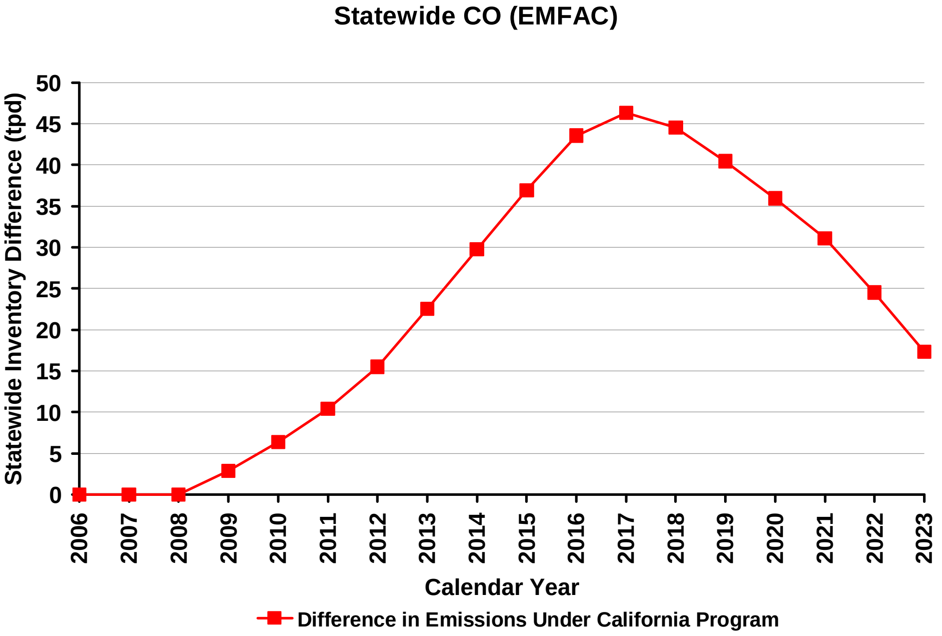

Figure E-7. Difference in Statewide emissions of CO under combined California Program (relative to emissions under Federal Program).

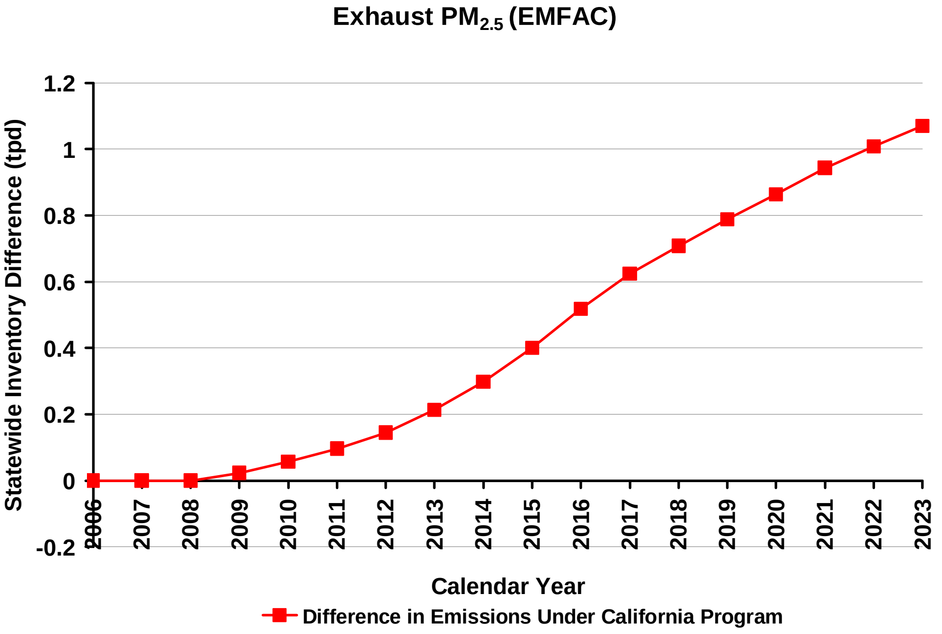

Figure E-8. Difference in Statewide emissions of exhaust $PM_{2.5}$ under combined California Program (relative to emissions under Federal Program).

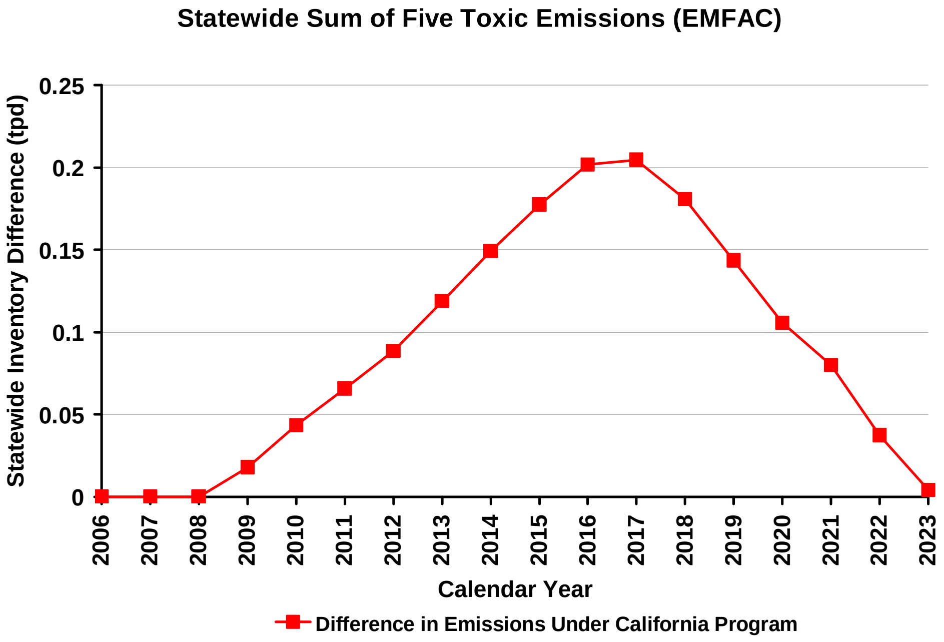

Figure E-9. Difference in Statewide sum of emissions of five toxic species under combined California Program (relative to emissions under Federal Program).

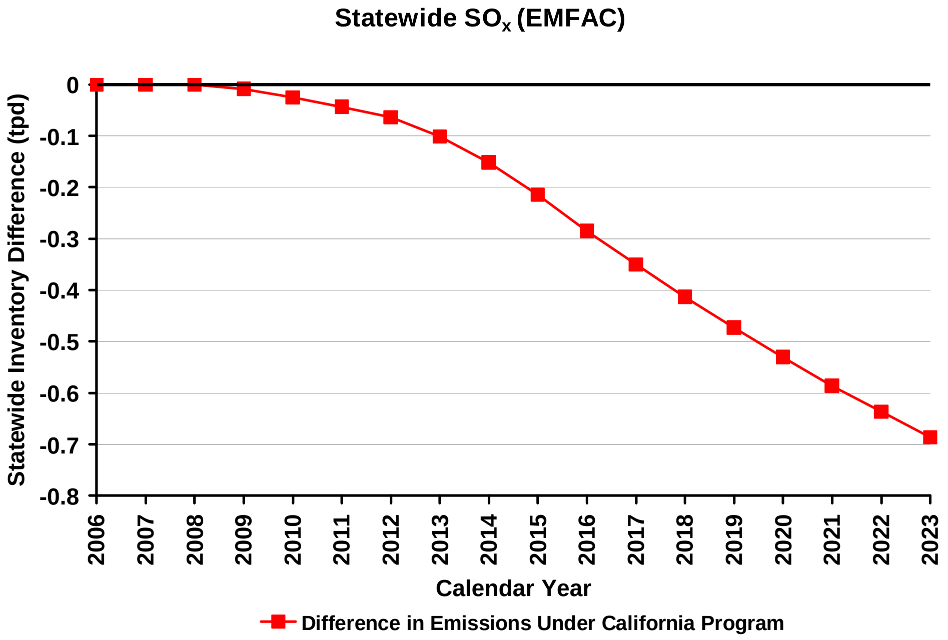

Figure E-10. Difference in Statewide emissions of SO_x under combined California Program (relative to emissions under Federal Program).

E.5.2. South Coast Air Basin Results

The following pages show plots of the difference in emissions of the California Program over the Federal Program, for the summer season, in tons per day, for all vehicles under 8500 lbs Gross Vehicle Weight Rating, in the South Coast Air Basin. Positive values indicate that the inventories under the California Program are higher than under the Federal Program. Negative values indicate that the inventories under the California Program are less than the Federal Program. The following charts are shown:

- VOC+NOx (Figure E-11);
- VOC (Figure E-12);
- NOx (Figure E-13);
- CO (Figure E-14);
- Exhaust $PM_{2.5}$ (Figure E-15);
- SO_x (Figure E-16); and,
- 5 Toxics Summed (Figure E-17).

The VOC+ NOx, VOC, NOx, CO, and PM2.5 charts have been adjusted for fuel cycle effects consistent with the discussion in Appendix G. The toxics and SOx charts have not been adjusted for fuel cycle effects.

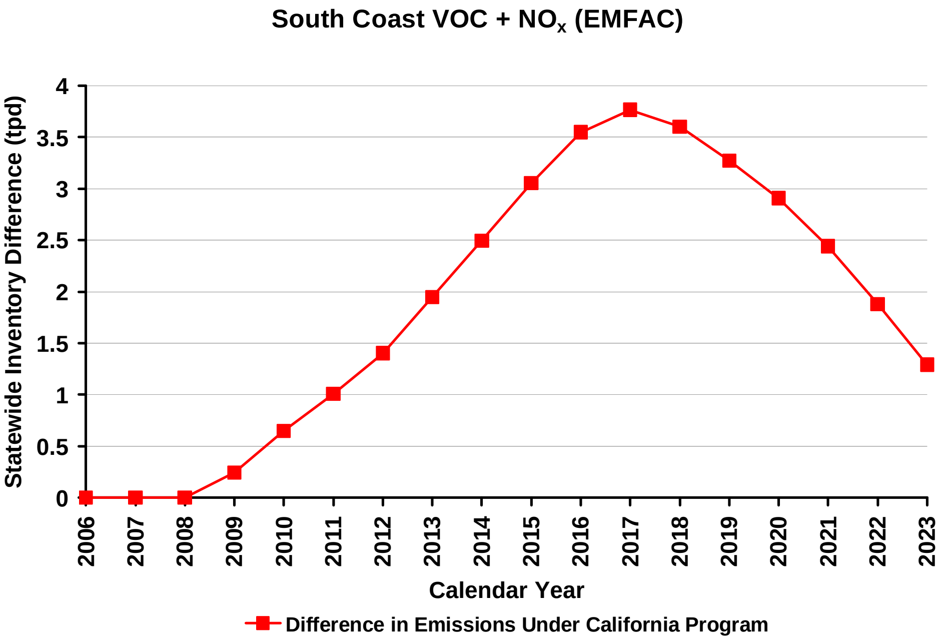

Figure E-11. Difference in South Coast emissions of VOC+NO_x under combined California Program (relative to emissions under Federal Program).

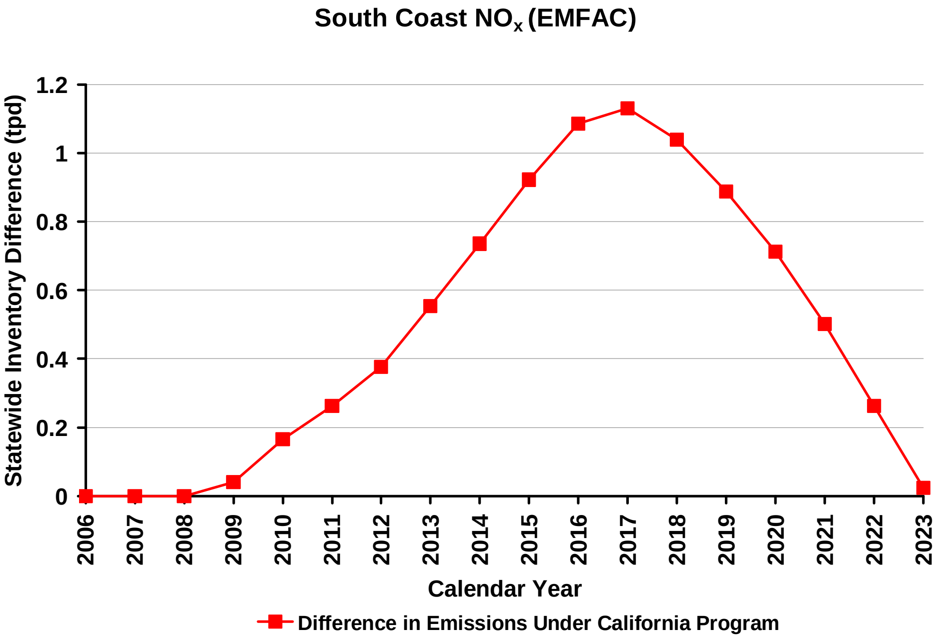

Figure E-12. Difference in South Coast emissions of NO_x under combined California Program (relative to emissions under Federal Program).

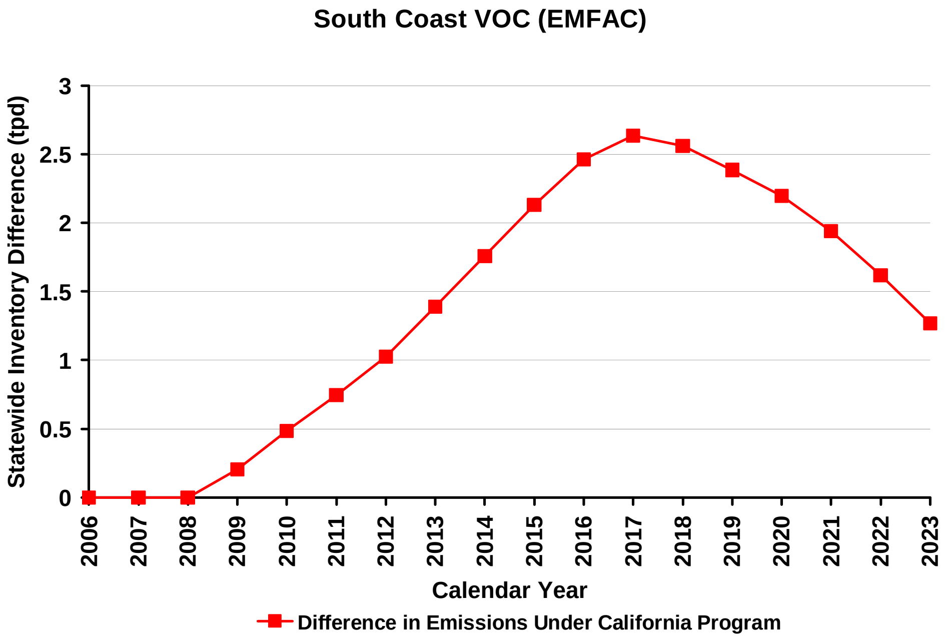

Figure E-13. Difference in South Coast emissions of VOC under combined California Program (relative to emissions under Federal Program).

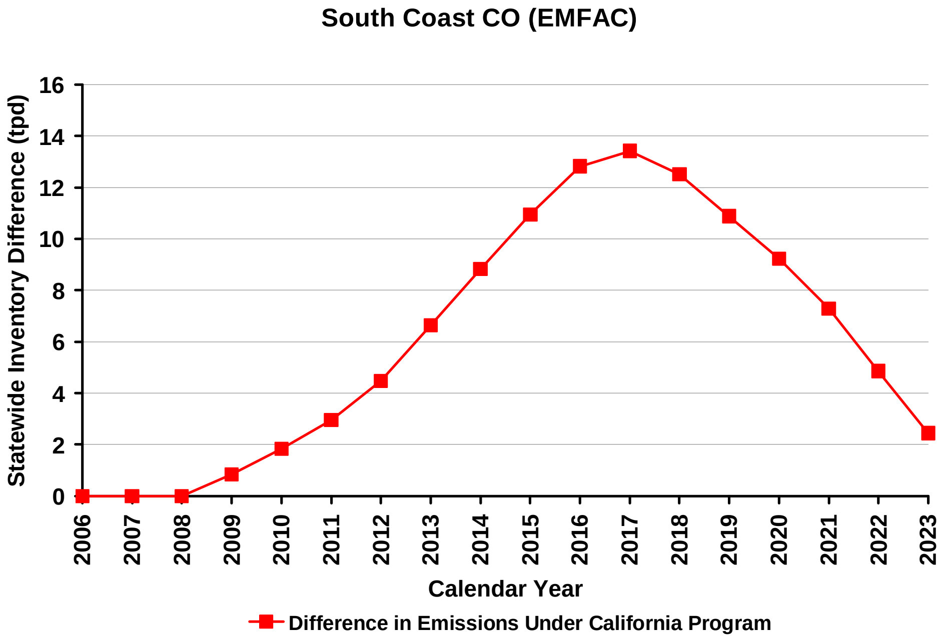

Figure E-14. Difference in South Coast emissions of CO under combined California Program (relative to emissions under Federal Program).

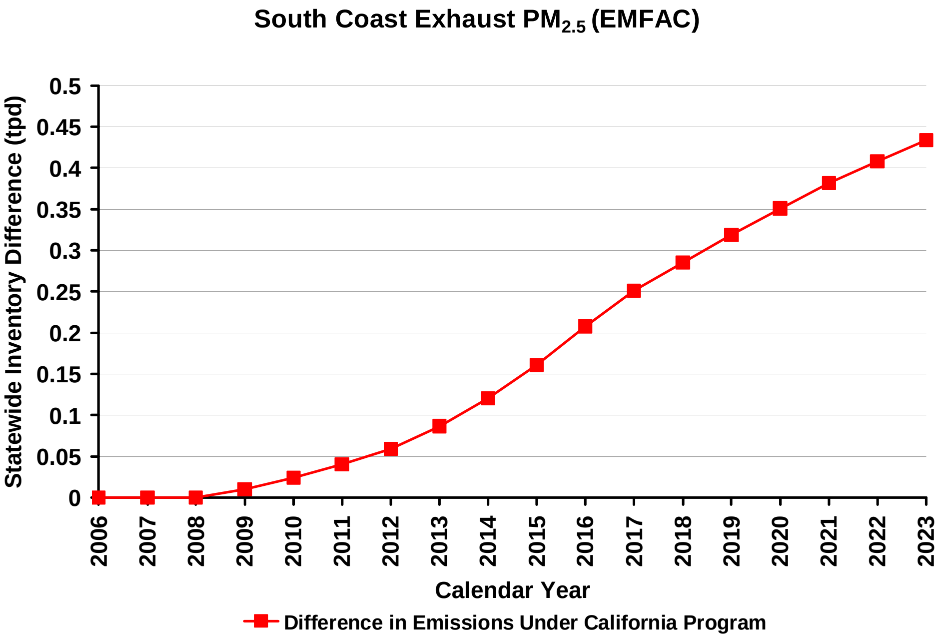

Figure E-15. Difference in South Coast exhaust emissions of PM$_{2.5}$ under combined California Program (relative to emissions under Federal Program).

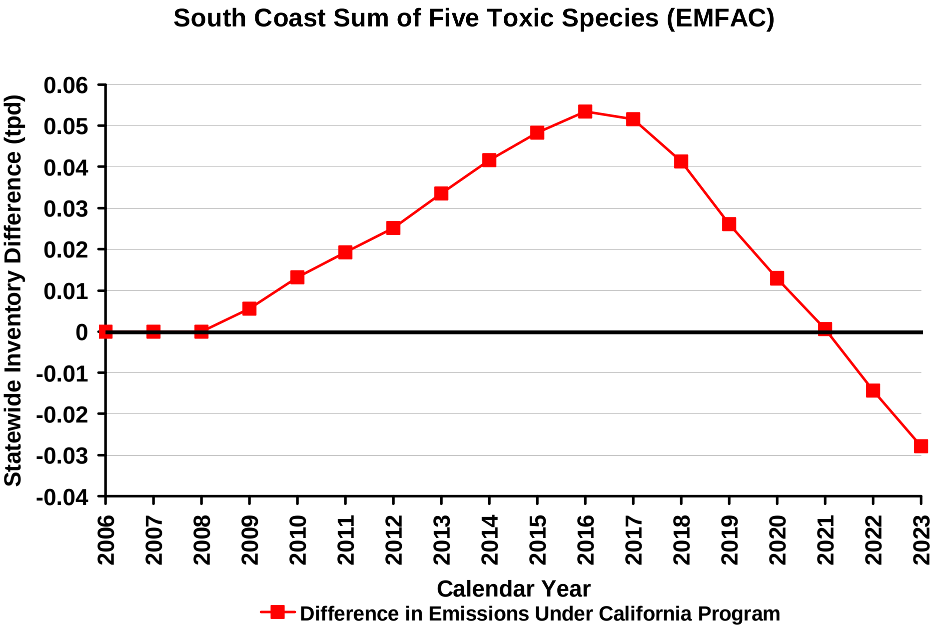

Figure E-16. Difference in South Coast sum of emissions of five toxic species under combined California Program (relative to emissions under Federal Program).

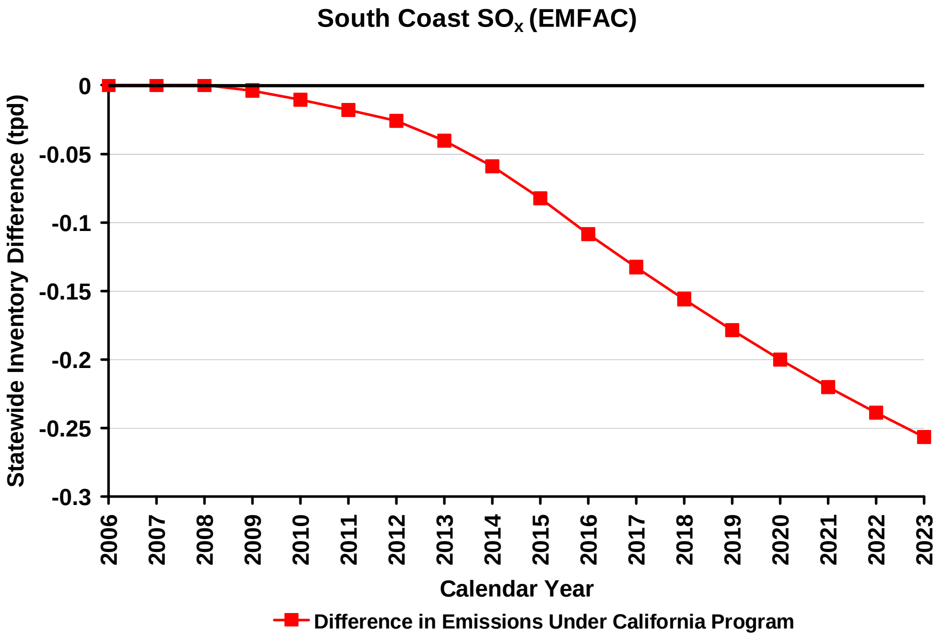

Figure E-17. Difference in South Coast emissions of SO_x under combined California Program (relative to emissions under Federal Program.

Appendix F. MOBILE6.2 Pollutant Emissions Modeling

The impacts of the California Program on California statewide and South Coast Air Basin ("SCAB") light-duty vehicle emissions were evaluated using U.S. EPA's MOBILE6.2 model.[32] Summer season inventory impacts were evaluated for calendar years 2006 to 2023 as, by that time, both the ZEV Standards and the GHG Standards programs will be fully phased-in and 2023 is the attainment deadline for the South Coast Air Basin with the ozone NAAQS. Emission inventories of ozone precursors (VOC and NOx) were prepared as well as those of other criteria pollutants (CO, SOx and $PM_{2.5}$) and five key air toxics (benzene, 1,3-butadiene, formaldehyde, acetaldehyde, and acrolein).

Emissions impacts were estimated by evaluating and comparing the following two regulatory scenarios:

1. Federal Tier 2 Program (baseline); and
2. California Program (including exhaust and evaporative emission standards, ZEV Standards, and GHG Standards).

The analysis and reported results of this document only include light-duty vehicles at or below 8,500 lbs. GVRW. These include the federal vehicle classes of passenger car (PC), light-duty truck 1 (LDT1), light-duty truck 2 (LDT2), light-duty truck 3 (LDT3) and light-duty truck 4 (LDT4). In this document we also define the term "medium duty vehicle" (MDV) as the sum of LDT3 and LDT4.[33]

The method and results of the MOBILE6.2 analysis are described in the following sections.

F.1. Method

The MOBILE6.2 modeling approach for the two regulatory scenarios was intended to emulate the parallel analysis completed with the EMFAC2007 model – described in Appendix E. However, unlike EMFAC2007, MOBILE6.2 is not a "self-contained" model, i.e., it does not contain vehicle population and VMT estimates that are needed to generate an emissions inventory in the units of tons per day. Instead, MOBILE6.2 provides gram-per-mile (g/mi)

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[32] Version MOBILE6.2.03 dated 24 September 2003.

[33] This MDV definition is consistent with vehicle categorization of the EMFAC2007 model.

emissions estimates that are then combined with VMT estimates outside of the model. Thereby, the combination of MOBILE6.2 emission rates with VMT data (i.e., the calculation of emission inventories) was handled within a spreadsheet post-processor for this analysis.

Overall, the application of two models (EMFAC2007 and MOBILE6.2) was implemented to determine if both models predict consistent results in quantifying the relative emissions impact of the California Program relative to the Federal Program.[34] In both models' analyses, the vehicle population and VMT assumptions were kept uniform, and therefore any resulting inventory differences would be due to differences in predicted emission rates from each model. The baseline VMT and vehicle populations used in the MOBILE6.2 analysis were those of the EMFAC2007 model, where "baseline" signifies the conditions in the absence of the fleet turnover and rebound effects resulting from the California Program—that is, conditions under the Federal Program. The extraction of these baseline data from EMFAC2007 are documented in Appendix E.

Notably, MOBILE6.2 is not structured to model any one specific geographic area, but rather has been structured to allow users to input numerous parameters to tailor the model to any geographic area of interest. Thus, in applying the MOBILE6.2 model for this analysis, it was necessary to develop the detailed modeling inputs specific to the South Coast Air Basin ("SCAB") and to California as a whole. The development of these MOBILE6.2 inputs is described next and is followed by the description of the approaches for modeling the fleet turnover and rebound effects with MOBILE6.2.

F.2. MOBILE6.2 Inputs

For consistency, the MOBILE6.2 input data were generally developed from the input data used in the EMFAC2007 model. The details of the MOBILE6.2 modeling input development are as described in the following sub-sections (identical values for each input parameter were used for both the California Program and the Federal Program except where specifically noted).

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[34] The MOBILE and EMFAC models have developed and evolved separately over several years, and the current versions of these models contain numerous structural, methodological and data differences. Therefore, the two models can produce distinct emission rate predictions under the same set of modeling conditions.

F.2.1. Vehicle Regulatory Standards

Assumed vehicle regulatory standards were modified accordingly to match the requirements of the California and Federal Programs. As noted earlier, the starting point for this analysis was the 2009 model year, and therefore for 2008-and-earlier model year vehicles, both scenarios relied on identical regulatory assumptions. The following describes the MOBILE6.2 regulatory assumptions used.

1. *2009-and-later model year vehicles (California program)* – The proportion of ZEV Mandate vehicles (i.e., PZEV, AT-PZEV and ZEV) by model year was based on the results of the New Vehicle Market Model. The remaining non-ZEV vehicles were assumed to follow the regulatory assumptions of the EMFAC2007 model. Adjustments were made to the proportions of the remaining vehicles to ensure compliance with fleet average NMOG standards in California. The resulting exhaust and evaporative compliance schedules by model year were incorporated into the MOBILE6.2 inputs files. These schedules are those also used in the EMFAC2007 analysis and are shown in Appendix E.

2. *2009-and-later model year vehicles (federal program)* – The MOBILE6.2 defaults for the federal Tier II program were used.

3. *2003 through 2008 model year vehicles* – The modeling of California standards with MOBILE6.2 was completed following EPA guidelines for those states opting into the California LEV II program (EPA 2002). California exhaust and evaporative standards were based on the MOBILE6.2 modeling inputs that accompany these guidelines. These regulatory assumptions and guidance are consistent with the regulatory assumptions in EMFAC2007.

4. *1994 through 2002 model year vehicles* – The modeling of California standards was completed by extracting out the assumed model year exhaust standards and technology groups from EMFAC2007 and placing these into the corresponding MOBILE6.2 input file for adjusting 1994-and-later model year vehicle exhaust standards. This input file allows for adjusting model year populations to assumed proportions meeting Tier 0, Tier 1, TLEV, LEV, ULEV and ZEV standards.

Prior to the 1994 model year, MOBILE6.2 does not allow for modifying vehicle regulatory standards through the model's input files, and no adjustments were made for these model years to account for differences between the California standards and the corresponding assumptions of the MOBILE6.2 model.

F.2.2. Ambient Conditions

Ambient conditions, consisting of hourly temperature and humidity values assumed by the model for summer season modeling, were extracted from EMFAC2007. The hourly data were incorporated into the MOBILE6.2 input files. Separate values were obtained for South Coast and statewide modeling. For the statewide values, EMFAC2007 uses a VMT-weighted average to generate the California-wide assumptions.

F.2.3. Fuel Parameters

California gasoline parameters were taken from the summer 2005 gasoline survey published by the Alliance of Automobile Manufacturers. Survey results by grade were weighted into a single composite based on California gasoline sales by grade published in the *Petroleum Marketing Annual 2005* (EIA 2006). MOBILE6.2 inputs for sulfur content, RVP, aromatic content, benzene content, olefin content, oxygenate content, E200 and E300 were obtained in this manner.

The Los Angeles survey data was used to define MOBILE6.2 fuel properties for the South Coast Air Basin. The California statewide properties were estimated by combining the Los Angles and San Francisco survey data in proportion to VMT.[35] The resulting MOBILE6.2 gasoline properties for the two modeling areas were nearly identical (e.g., RVP of 7.0 psi, sulfur content less than 9 ppm, benzene content of about 0.5%, and 100 percent ethanol-blend market share at 5.7 volume percent ethanol).

F.2.4. Vehicle Operation Characteristics

Several vehicle operating characteristics were extracted from EMFAC2007 output files from specifically designed model runs to define corresponding MOBILE6.2 input parameters.

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[35] The Los Angeles survey was used to represent those California areas covered by federal reformulated gasoline regulations (representing 89 percent of the state VMT) and San Francisco was used to represent the areas not covered by this federal requirement (11 percent of state VMT).

EMFAC2007 results were compiled for both statewide and South Coast operation for calendar year 2006 – including results detailed by speed, hour-of-day and vehicle age – as needed to process into specific MOBILE6.2 parameters under summer weekday conditions. The following MOBILE6.2 input parameters were defined in this manner:[36]

1. *Speed Distributions* – the normalized proportion of VMT by 5-mph speed bin for each hour of day,

2. *Starts per Day* - the average number of engine starts per vehicle per day as a function of vehicle class and vehicle age,

3. *Hourly VMT Distributions* – the normalized proportion of VMT by hour of day, and

4. *Hourly Trip Distributions* – the normalized proportion of trips by hour of day.

F.2.5. Mileage Accumulation Rates and Registration Distributions

MOBILE6.2 mileage accumulation rates and registration distributions were also based on data extracted from EMFAC2007. Mileage accumulation rates are average annual miles driven by vehicle class by vehicle age; registration distributions are the normalized age distributions of vehicle populations by vehicle class. For these two parameters, the values modeled varied by regulatory scenarios.

For the Federal Program the baseline EMFAC2007 data were used. For the California Program, the rebound and fleet turnover effects were factored into the registration distribution and mileage accumulation rates of the scenario. The method for making these adjustments is described below. Notably, for these two parameters, the values incorporated into MOBILE6.2 were specific to each calendar year (2006 through 2023).

F.2.6. I/M Program Parameters

The MOBILE6.2 I/M program modeling parameters were taken from those used by the U.S. EPA for the 2002 National Emission Inventory (NEI) effort (EPA 2005). The 2002 NEI based

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[36] EMFAC2007 data for calendar year 2006 were used to define the parameters listed. These were then used for modeling all calendar years in the MOBILE6.2 analysis (2006 through 2023); of these parameters only the speed distribution of EMFAC2007 can vary by calendar year for some areas of California.

inputs were reviewed for consistency with the EMFAC2007 modeling assumptions. The program includes an anti-tampering inspection, ASM tailpipe testing and OBD testing requirements.

F.2.7. Particulate Matter Emission Rates

MOBILE6.2 default PM emission rates have been carried over from successive versions of EPA models for some time and have not been updated significantly in 20 years (mid-1980's test data). EPA recognized the need to potentially update the PM emission rate assumptions in MOBILE6.2 and made PM the only criteria pollutant for which alternate emission rate assumptions can be handled through the model input. However, EPA has not provided to date any updates to the PM emission rates of MOBILE6.2.

Sierra Research developed updated light-duty vehicle PM emission rates for the Western Regional Air Partnership. These were based on more recently collected test data – much of which was California-based (Sierra 2001). These PM emission rate updates were used in this analysis as well and were incorporated into the MOBILE6.2 PM emission rate inputs files. Notably, the PM emission rates included a deterioration rate based on the assumption that 9 percent of the fleet would be high emitters at the 10 year-old mark (equal to about 150,000 accumulated miles based on the mileage accumulation rates of EMFAC2007).

F.3. Fleet Turnover Effects

The fleet turnover effect impacts only the California program scenario resulting in changes to the fleet composition as determined by the New Vehicle Market Model and the Scrappage Model. The vehicle population changes due to the fewer new sales and a greater retention of older vehicles (relative to the Federal Program). Overall, there is typically a net loss in the total number of vehicles of one to two percent or less. These impacts were incorporated into the MOBILE6.2 analysis as follows.

1. *Registration Distributions* – The registration distributions of the California program scenario were recalculated based on the scenario fleet composition data factoring in the fleet turnover effect.

2. *VMT* – Overall, the fleet turnover effect results in the conservation of VMT in that total VMT demand would be unaffected remains unchanged from the baseline (federal program

scenario). However, the proportions of VMT by vehicle class and vehicle age are adjusted to account for the changes in fleet composition. These changes were incorporated into the spreadsheet post-processor used to calculate emission inventories in the MOBILE6.2 analysis. All vehicles were assumed to make up any VMT shortfall (due to a net reduction in overall fleet population) by driving a bit more per vehicle – but the relative proportions between mileage accumulation rates were retained so that newer vehicles are driven more than older vehicles in making up any additional VMT per vehicle.

F.4. Rebound Effects

The rebound effect is relevant only for the California Program—resulting in increased VMT for those vehicles with increased fuel economy over the baseline (because these vehicles are less expensive to operate). The rebound effect was incorporated into the MOBILE6.2 analysis as follows.

1. *VMT* – The VMT driven by 2009-and-later model year vehicles under the California Program were modified to include the estimated rebound VMT. This change was made to the spreadsheet post-processor model.

2. *Mileage Accumulation Rates* – For 2009-and-later model year vehicles only, the MOBILE6.2 mileage accumulation rates were modified for consistency of the rebound VMT resulting is slightly greater mileage accumulation rates for this model year group in the California program scenario.

F.5. Results

The MOBILE6.2 analysis inventory results are discussed in the following sub-sections. South Coast Air Basin results are presented first, followed by the California statewide results. The inventory results are presented as the difference between the California Program and the Federal Program, where a *positive* difference signifies an *increase in emissions* under the California program. Results shown are summer season tons per day for light-duty vehicles (<8500 lbs GVWR).

F.5.1. South Coast Air Basin

The following inventory difference plots are presented for the South Coast Air Basin including the rebound and fleet turnover effects:

Figure F-1: ozone precursor emissions (VOC & NOx),
Figure F-2: CO emissions,
Figure F-3: $PM_{2.5}$ emissions,
Figure F-4: SOx emissions, and
Figure F-5: toxics emissions (sum of 5 species).

These results show that the California program results in higher emissions for all pollutants except SOx. SOx emissions are lower due to reduced fuel consumption under the California Program.

The results shown in Figures F-1 through F-5 do not factor in the fuel cycle emissions, which are generally lower under the California Program. The following figures include the fuel cycle effects (as estimated in Appendix G for ozone precursors, CO and PM).

Figure F-6: ozone precursor emissions (VOC & NOx),
Figure F-7: CO emissions, and
Figure F-8: $PM_{2.5}$ emissions.

When the fuel cycle effects are included, the inventory results for the California program scenario are still greater than those of the federal program.

F.5.2. California

A corresponding set of inventory difference plots are also presented for the California statewide results including the rebound and fleet turnover effects:

Figure F-9: ozone precursor emissions (VOC & NOx),
Figure F-10: CO emissions,
Figure F-11: $PM_{2.5}$ emissions,
Figure F-12: SOx emissions, and
Figure F-13: toxics emissions (sum of 5 species).

These results show similar results to those of the South Coast Air Basin. The California program scenario emissions are generally greater than those of the federal scenario. The exceptions to this are SOx emissions and toxics (calendar year 2023 only).

The following figures incorporate the fuel cycle effects (as estimated in Appendix G for ozone precursors, CO and PM) into the California statewide results.

Figure F-14: ozone precursor emissions (VOC & NOx),
Figure F-15: CO emissions, and
Figure F-16: $PM_{2.5}$ emissions.

When the fuel cycle effects are included, the inventory results for the California program scenario are still greater than those of the federal program.

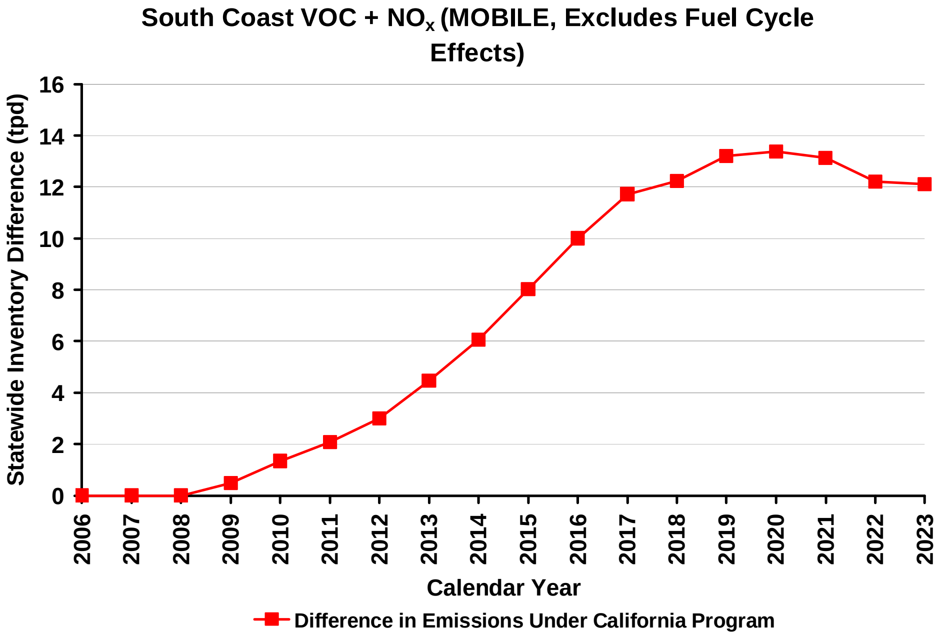

Figure F-1. Difference in South Coast emissions of VOC+NOx under combined California Program (relative to emissions under Federal Program), not accounting for fuel cycle effects

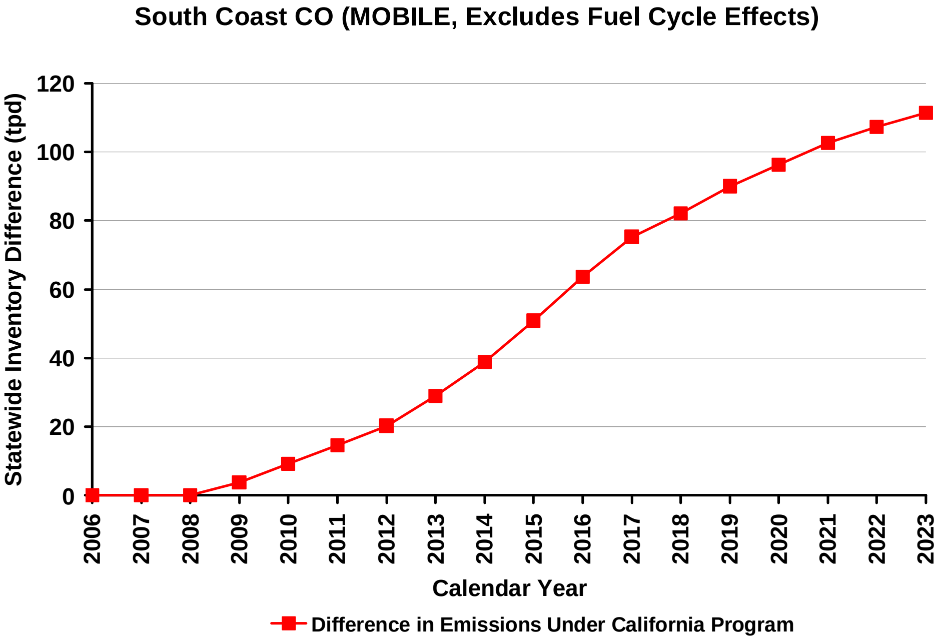

Figure F-2. Difference in South Coast emissions of CO under combined California Program (relative to emissions under Federal Program), not accounting for fuel cycle effects.

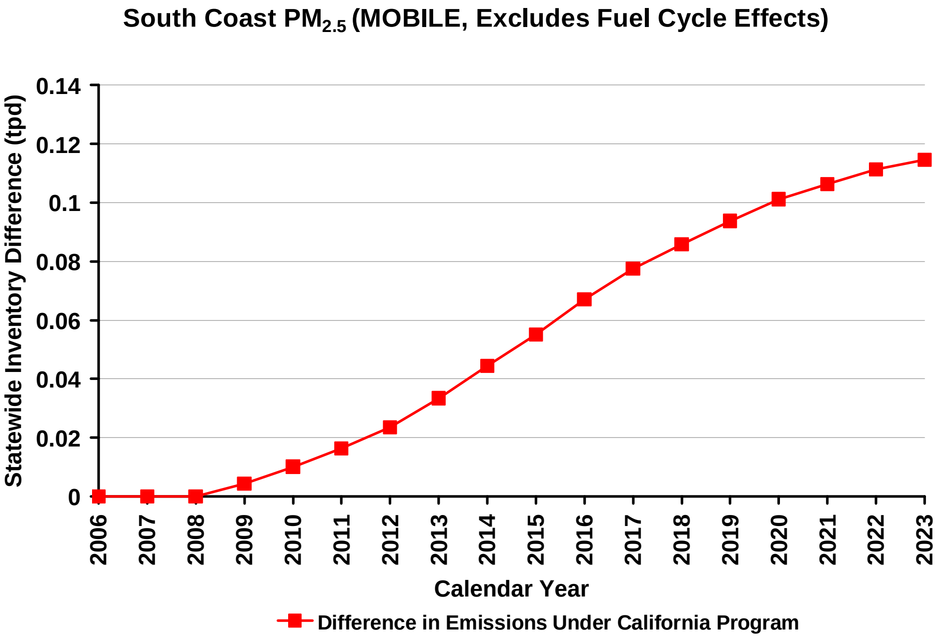

Figure F-3. Difference in South Coast emissions of PM2.5 under combined California Program (relative to emissions under Federal Program), not accounting for fuel cycle effects.

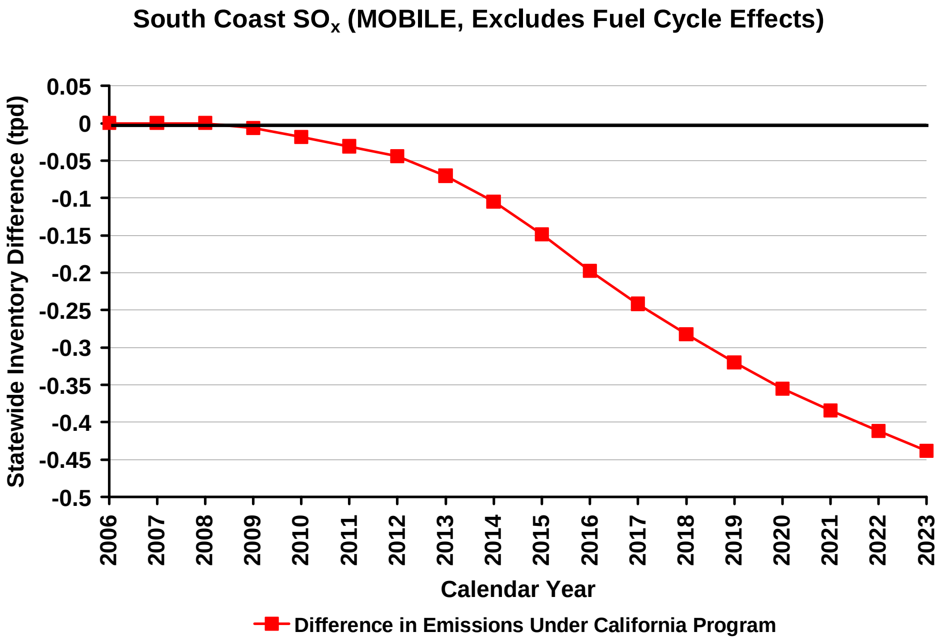

Figure F-4. Difference in South Coast emissions of SO_x under combined California Program (relative to emissions under Federal Program), not accounting for fuel cycle effects.

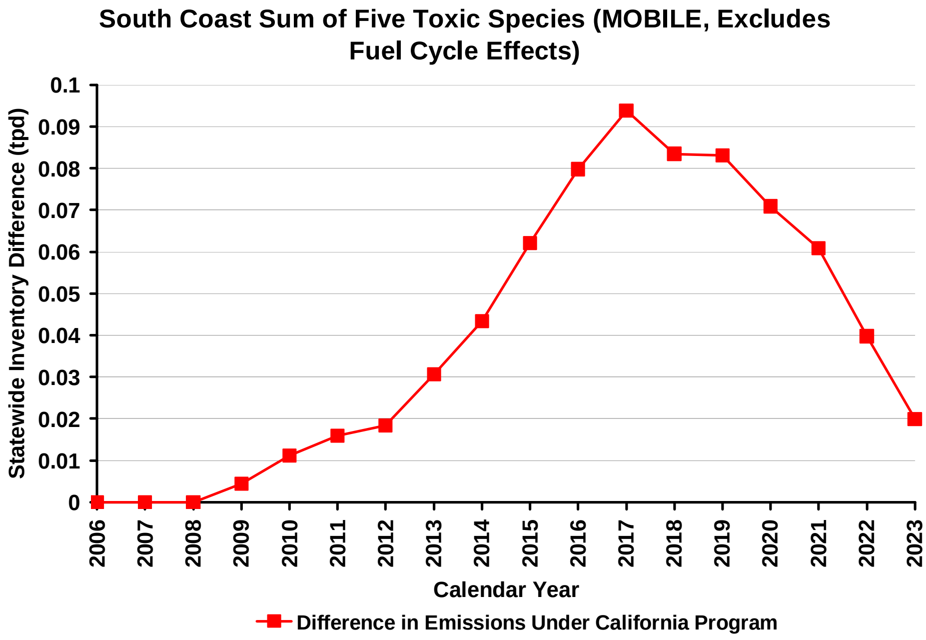

Figure F-5. Difference in South Coast emissions of 5 air toxics under combined California Program (relative to emissions under Federal Program), not accounting for fuel cycle effects.

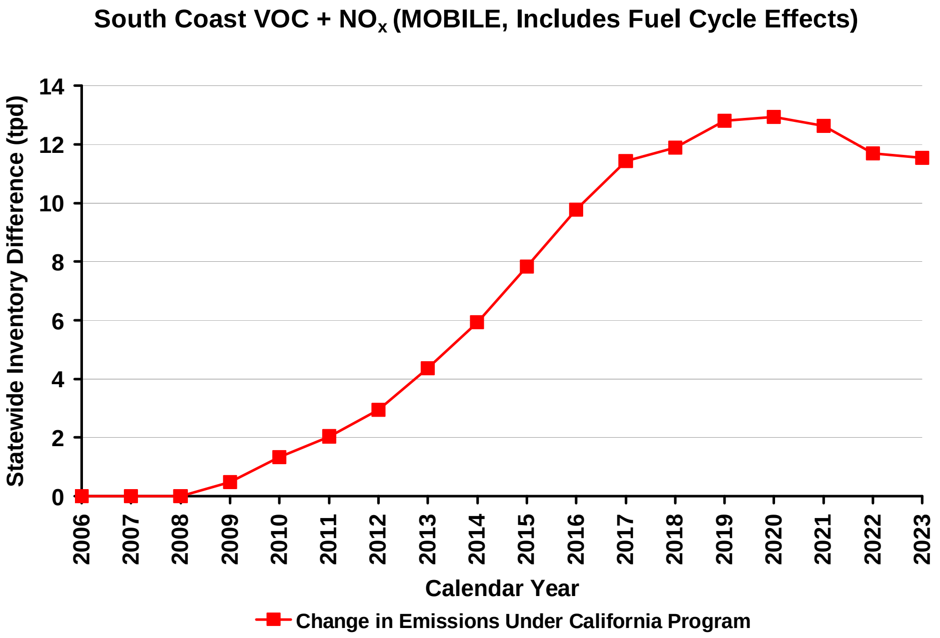

Figure F-6. Difference in South Coast emissions of VOC+NOx under combined California Program (relative to emissions under Federal Program), accounting for fuel cycle effects.

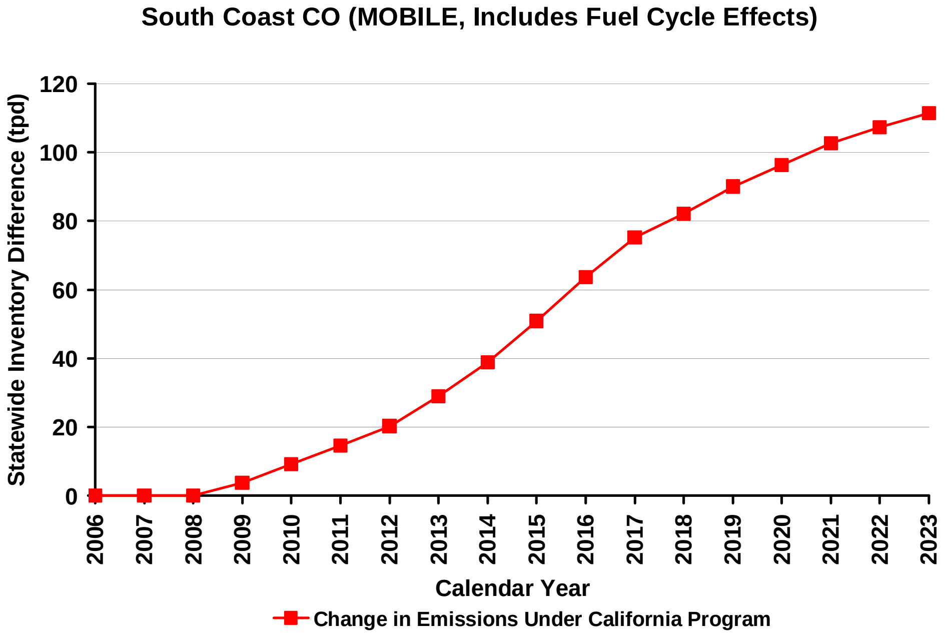

Figure F-7. Difference in South Coast emissions of CO under combined California Program (relative to emissions under Federal Program), accounting for fuel cycle effects.

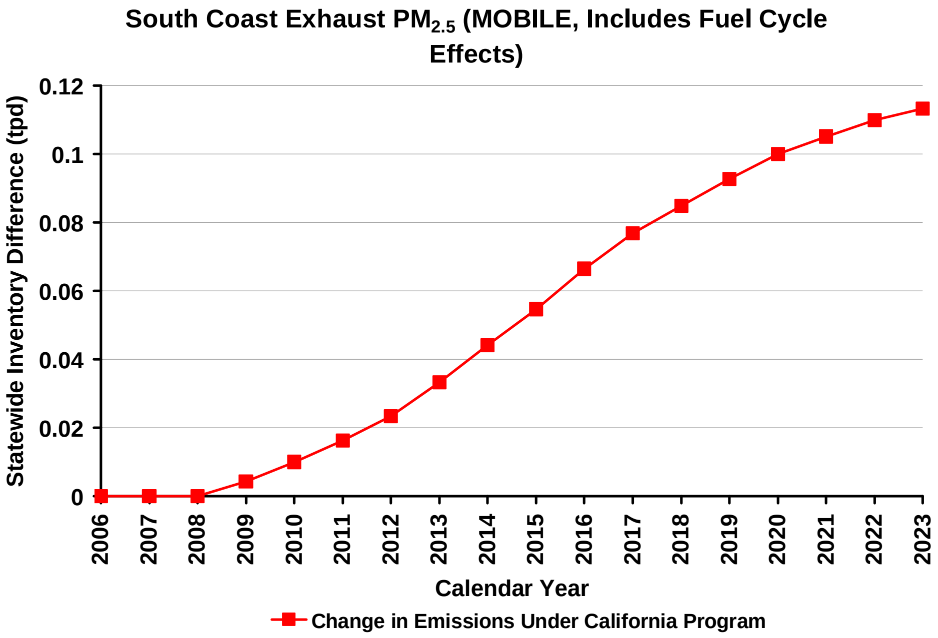

Figure F-8. Difference in South Coast emissions of $PM_{2.5}$ under combined California Program (relative to emissions under Federal Program), accounting for fuel cycle effects.

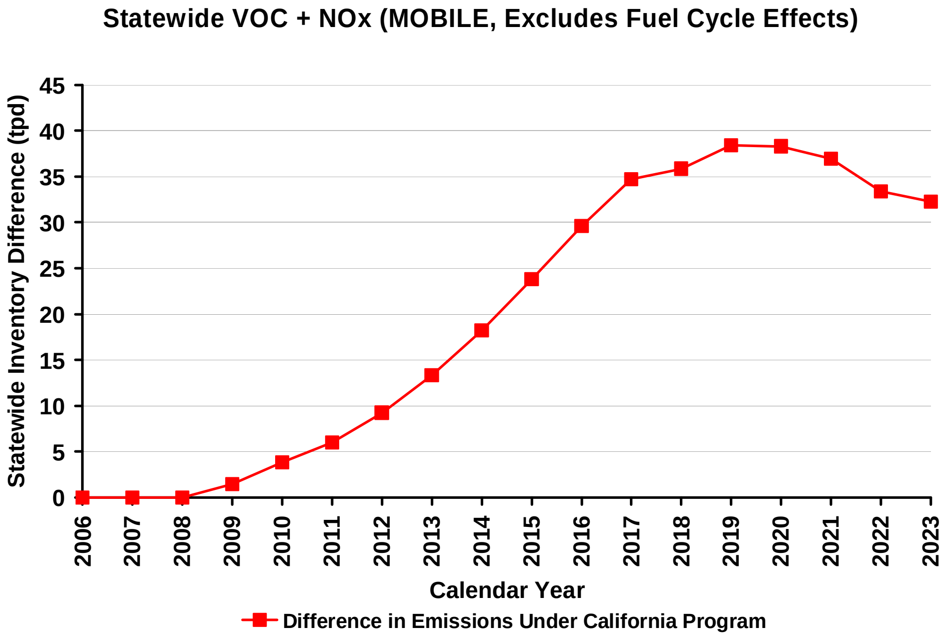

Figure F-9. Difference in California emissions of VOC+NOx under combined California Program (relative to emissions under Federal Program), not accounting for fuel cycle effects.

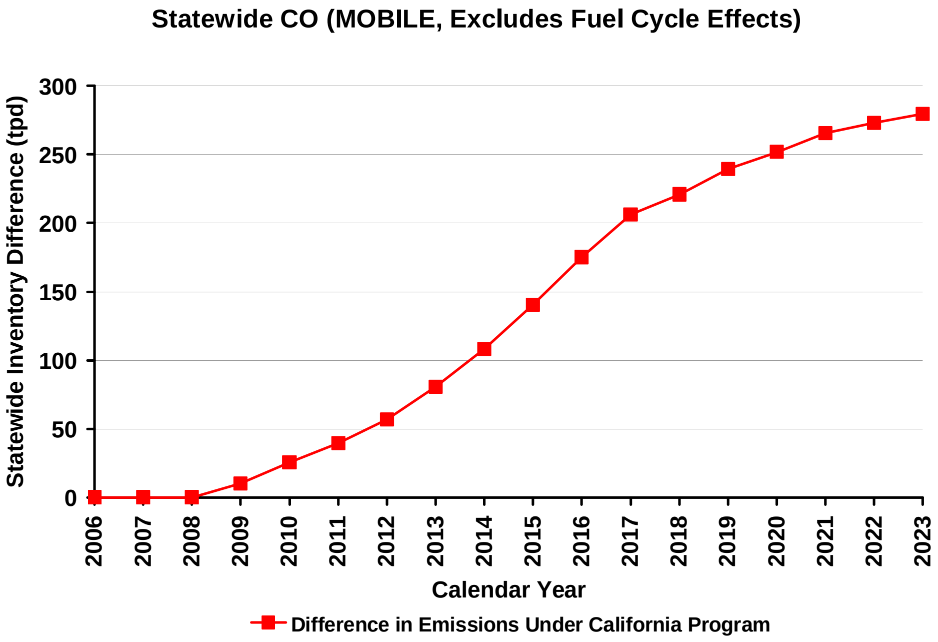

Figure F-10. Difference in California emissions of CO under combined California Program (relative to emissions under Federal Program), not accounting for fuel cycle effects.

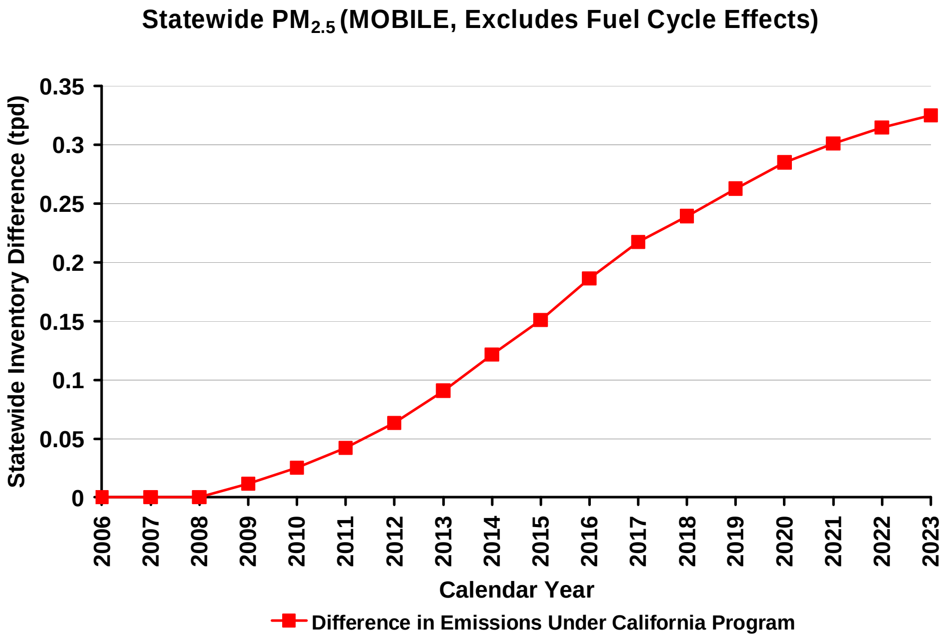

Figure F-11. Difference in California emissions of $PM_{2.5}$ under combined California Program (relative to emissions under Federal Program), not accounting for fuel cycle effects.

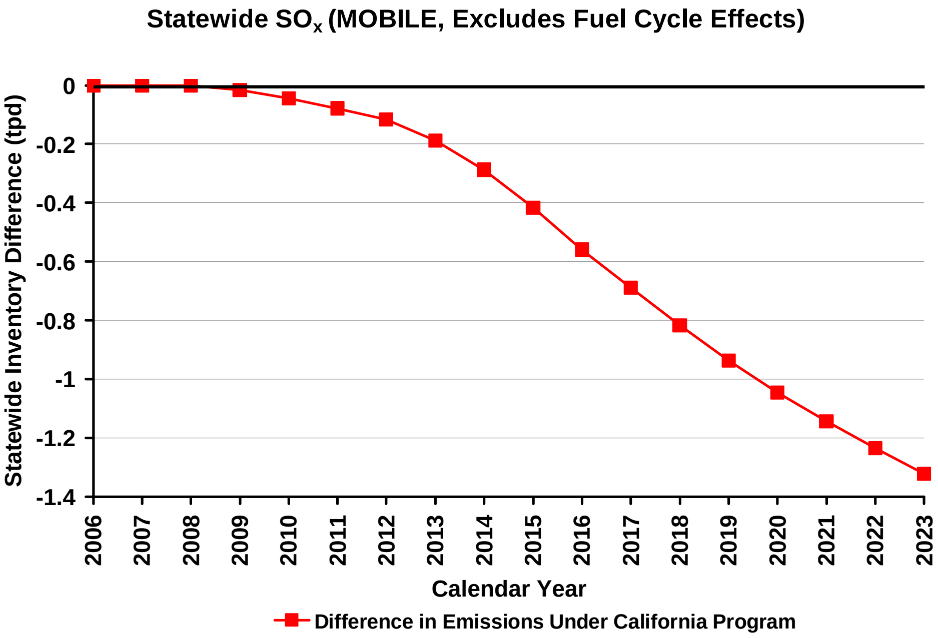

Figure F-12. Difference in California emissions of SO_x under combined California Program (relative to emissions under Federal Program), not accounting for fuel cycle effects.

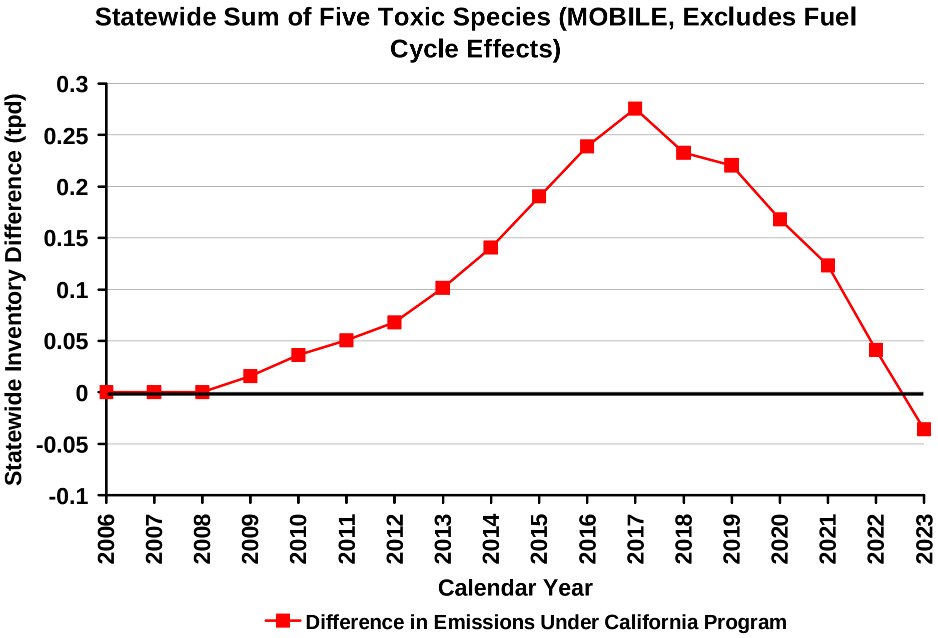

Figure F-13. Difference in California emissions of 5 air toxics under combined California Program (relative to emissions under Federal Program), not accounting for fuel cycle effects.

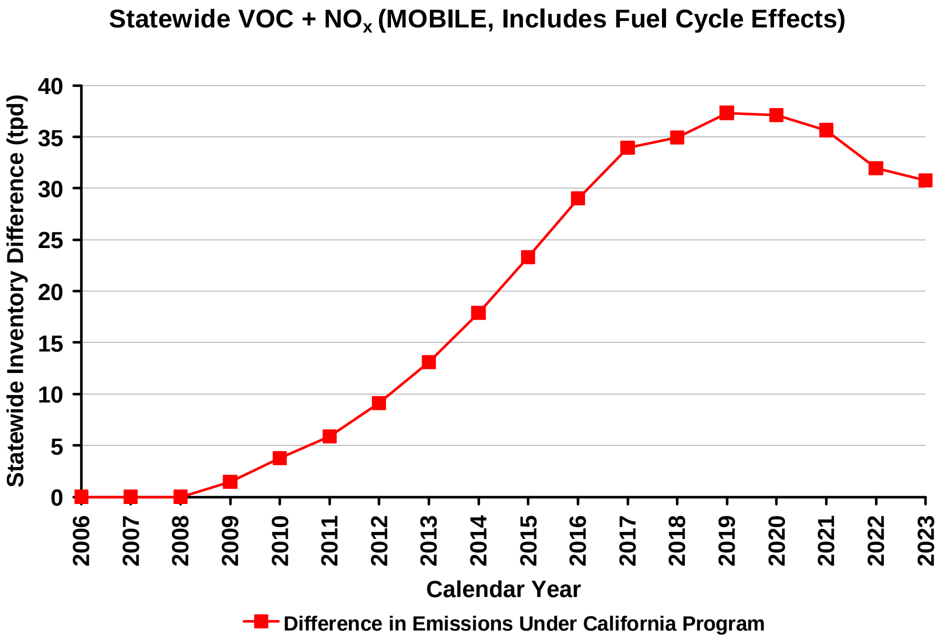

Figure F-14. Difference in California emissions of VOC+NOx under combined California Program (relative to emissions under Federal Program), accounting for fuel cycle effects.

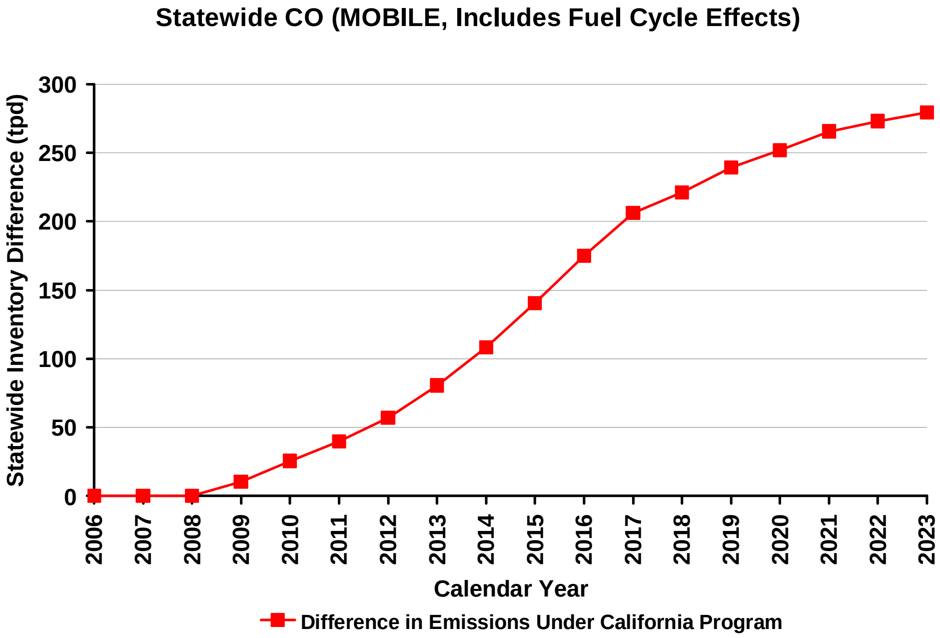

Figure F-15. Difference in California emissions of CO under combined California Program (relative to emissions under Federal Program), accounting for fuel cycle effects.

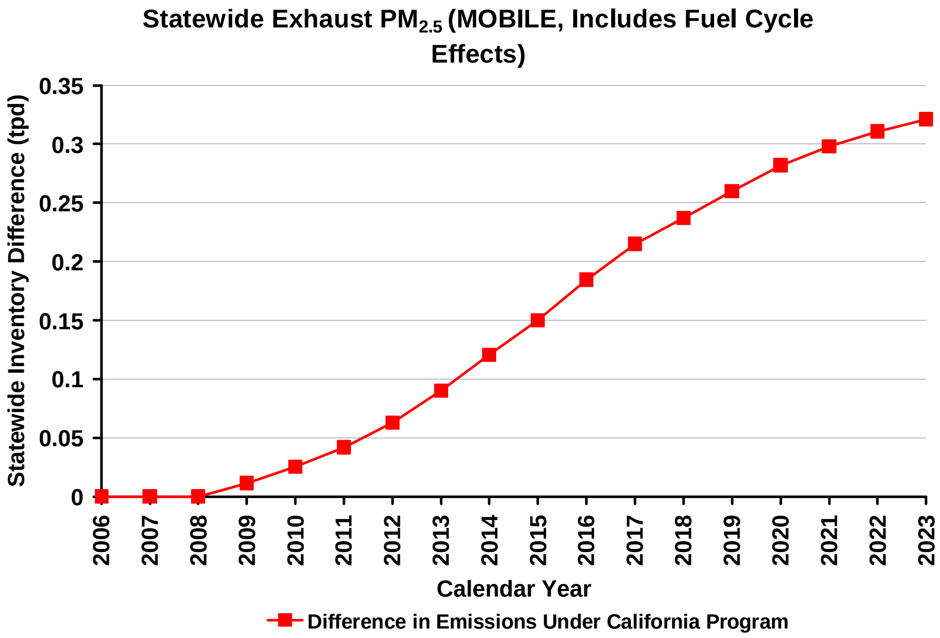

Figure F-16. Difference in California emissions of VOC+NOx under combined California Program (relative to emissions under Federal Program), accounting for fuel cycle effects.

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Appendix G. Emissions Impacts Associated with Reduced Gasoline Consumption

The term “fuel cycle emissions” (sometimes called “upstream emissions”) is related to a concept whereby the criteria emissions associated with the use of different types of vehicular fuels (e.g., gasoline) are assessed starting at the point that production of the fuel begins--in this case, a petroleum well--and continuing through the delivery of the fuel to a vehicle. The following are potential sources of fuel cycle emissions associated with the use of gasoline:

1. Extraction of petroleum;
2. Transport of petroleum to a refinery;
3. Production of gasoline at a refinery;
4. Transport and storage of gasoline; and
5. Gasoline marketing.

In analyzing fuel cycle emissions differences between the two regulatory scenarios of interest, the key factor is the effect of the California regulation on the fuel economy of new vehicles. Reduced fuel consumption translates into reduced fuel cycle emissions. The following sections examine the upstream criteria emissions associated with gasoline consumption of the federal and California regulatory scenarios.[37]

G.1. Method

The primary regulatory driver affecting gasoline consumption is the GHG Standard. The method used in this study generally follows that of CARB in its Initial Statement of Reasons (ISOR) (CARB 2004) with significant changes to the fuel cycle emission factors to correct for errors made by CARB.

We have already completed an extensive review of the fuel cycle methods employed by CARB in the regulatory process for the GHG Standards, which is not repeated here (Sierra 2005). In brief, CARB staff estimates of fuel cycle emissions changed multiple times as updates were published to correct for staff errors (CARB 2004a), with the staff’s final assessment being that

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[37] Note that we do not account for fuel cycle emissions associated with the production and delivery of hydrogen. Thus, our estimates overstate the emissions reductions of the California program due to fuel cycle effects.

published on October 19, 2004 in CARB's first 15-Day Notice for the California GHG regulations (CARB 2004b). Specifically, final estimates were contained in Attachment II to the 15-Day Notice entitled "Additional Supporting Documents and Information." We found that significant flaws continued to exist in the 15-Day Notice version of the staff's emission factor estimates – most significant were the assumed fleet characteristics of fuel delivery trucks and assumed transit distances traveled. These assumptions conflicted with both other CARB regulatory estimates as well as those used by the South Coast Air Quality Management District ("SCAQMD") and resulted in a significant overestimate of fuel cycle emissions (up to a factor of 4).

We have estimated revised gasoline fuel cycle emission factors correcting for the errors made in CARB's assessments of the GHG Standards. These factors, specific to California gasoline production and delivery, are presented in Table G-1 and represent the criteria emissions in grams of pollutant per gallon of fuel delivered. Emission factors are reported as a range reflecting the valid range of underlying assumptions.

Table G-1. California Fuel Cycle Emission Factors (grams/gallon)

Pollutant	Low-End Estimate	High-End Estimate
NO_X	0.010	0.035
CO	0.006	0.009
NMOG	0.190	0.213
PM	0.0003	0.0008

Fuel cycle emissions were estimated from the combination of emission factors and estimated gasoline consumption under two scenarios (the Federal Program and the California Program). Fuel consumption was estimated in two ways: first, following the methods of the EMFAC2007 model, and second, following the methods of MOBILE6.2. Fuel consumption was calculated as part of each model's emission inventory assessment of the two regulatory scenarios (as described in Appendix E and Appendix F, respectively). For the California Program, the fuel economy of 2009-and-later model year vehicles increases over that under the Federal Program. The percent change in model year fuel economy is shown in Table G-2 and includes the impacts of both the ZEV Standards and the GHG Standards. These fuel economy changes were incorporated into the emission inventory analysis of each model, fuel economy was converted to fuel consumption using VMT data, and the resulting fuel consumption estimates included both the rebound and fleet turnover effects of the California program.

Table G-2. Percent Increase in Model Year Fuel Economy California Program Over the Federal Program

Model Year	PC	LDT1	LDT2	MDV
2009	4.21%	0.88%	0.45%	0.42%
2010	7.25%	2.53%	2.32%	2.30%
2011	8.83%	3.44%	2.99%	2.96%
2012	10.43%	4.36%	3.66%	3.63%
2013	17.40%	7.54%	7.56%	7.53%
2014	24.70%	10.77%	11.56%	11.54%
2015	32.62%	14.29%	15.70%	15.65%
2016	40.61%	17.62%	19.90%	19.86%
2017	40.59%	17.61%	19.90%	19.86%
2018	40.54%	17.63%	19.90%	19.86%
2019	40.53%	17.62%	19.90%	19.86%
2020	40.51%	17.60%	19.90%	19.86%
2021	40.52%	17.64%	19.90%	19.86%
2022	40.50%	17.63%	19.90%	19.86%
2023	40.49%	17.61%	19.90%	19.86%

G.2. Results

The estimated summer season daily fuel consumption is presented in Table G-3 and Table G-4 for California statewide and the South Coast Air Basin, respectively. For the statewide total, the California program is estimated to result in a reduction of about 6 to 7 million gallons by 2023. In general, the fuel consumption estimates for EMFAC2007 are greater than those of MOBILE6.2 as the underlying fuel economy of a given model year vehicle is less in the EMFAC model. For the South Coast, the results are similar to those reported for the state where the district makes up between 38 and 42 percent of the statewide fuel consumption – depending on calendar year.

Table G-3. California Statewide Fuel Consumption (Gallons/Day) Vehicles at or below 8,500 Lbs GVRW, Summer Season

Calendar Year	MOBILE6.2 Model Results			EMFAC2007 Model Results		
	Federal Program	California Program	Difference (California Program Reduction)	Federal Program	California Program	Difference (California Program Reduction)
2006	41,345,835	41,345,835	0	48,362,184	48,362,184	0
2007	40,892,899	40,892,899	0	47,712,624	47,712,624	0
2008	41,234,450	41,234,450	0	47,926,581	47,926,581	0
2009	41,734,053	41,652,604	81,449	48,357,727	48,263,761	93,966
2010	42,275,427	42,040,716	234,712	48,932,238	48,661,616	270,622
2011	42,817,673	42,412,982	404,691	49,681,856	49,213,577	468,279
2012	43,430,712	42,834,934	595,778	50,306,258	49,617,299	688,960
2013	44,121,678	43,182,355	939,323	51,015,386	49,928,172	1,087,213
2014	44,769,097	43,368,974	1,400,123	51,736,997	50,111,993	1,625,004
2015	45,425,477	43,449,581	1,975,897	52,473,466	50,178,603	2,294,863
2016	45,974,687	43,370,552	2,604,135	53,278,925	50,234,473	3,044,453
2017	46,536,490	43,339,924	3,196,566	53,906,595	50,168,629	3,737,966
2018	47,172,230	43,406,066	3,766,164	54,582,716	50,175,377	4,407,339
2019	47,822,658	43,514,333	4,308,325	55,290,638	50,246,275	5,044,363
2020	48,465,572	43,637,284	4,828,288	56,025,925	50,373,053	5,652,872
2021	49,049,620	43,745,545	5,304,075	57,023,110	50,772,275	6,250,835
2022	49,635,646	43,869,393	5,766,253	57,698,418	50,905,087	6,793,332
2023	50,301,298	44,096,362	6,204,936	58,402,067	51,087,087	7,314,980

Table G-4. South Coast Air Basin Fuel Consumption (Gallons/Day) Vehicles at or below 8,500 Lbs GVRW, Summer Season

Calendar Year	MOBILE6.2 Model Results			EMFAC2007 Model Results		
	Federal Program	California Program	Difference (California Program Reduction)	Federal Program	California Program	Difference (California Program Reduction)
2006	17,225,854	17,225,854	0	20,433,167	20,433,167	0
2007	16,696,744	16,696,744	0	19,745,178	19,745,178	0
2008	16,824,126	16,824,126	0	19,748,543	19,748,543	0
2009	16,938,564	16,903,372	35,192	19,849,687	19,808,576	41,110

2010	17,051,054	16,953,648	97,406	19,957,842	19,844,056	113,786
2011	17,196,138	17,032,733	163,405	20,235,288	20,043,377	191,912
2012	17,367,352	17,131,287	236,065	20,405,868	20,128,931	276,937
2013	17,576,114	17,208,789	367,325	20,617,685	20,186,643	431,042
2014	17,720,304	17,184,076	536,228	20,800,821	20,169,214	631,606
2015	17,881,368	17,133,238	748,130	20,979,770	20,097,840	881,929
2016	17,984,445	17,008,457	975,988	21,176,940	20,018,920	1,158,020
2017	18,104,588	16,912,277	1,192,311	21,311,890	19,896,455	1,415,435
2018	18,259,336	16,857,394	1,401,942	21,474,472	19,808,673	1,665,799
2019	18,426,840	16,823,765	1,603,076	21,657,424	19,751,473	1,905,951
2020	18,598,760	16,801,682	1,797,078	21,856,886	19,719,989	2,136,897
2021	18,706,077	16,740,797	1,965,280	22,078,440	19,729,218	2,349,222
2022	18,824,076	16,693,977	2,130,100	22,215,541	19,669,682	2,545,859
2023	18,972,281	16,685,619	2,286,663	22,366,452	19,631,570	2,734,882

The reduction in fuel consumption under the California program was converted into a reduction in fuel cycle emissions. The results are presented in Table G-5 and Table G-6 for California and the South Coast Air Basin, respectively. Results are reported as a range where the low-end estimate is based on the low-end emission factor (see Table G-2) and the MOBILE6.2-based fuel consumption differences. Accordingly, the high-end estimate is based on the high-end emission factor and EMFAC2007-based fuel consumption differences. By 2023, the statewide reduction is estimated between 1.3 and 1.6 tpd for NMOG, between 0.07 and 0.28 tpd for NOx, between 0.04 and 0.07 tpd for CO, and between 0.002 and 0.006 tpd for PM. For the South Coast, the results are similar to those reported for the state with reported reductions in approximate proportion to the district’s share of the state fuel consumption (between 38 and 42 percent of the state total).

Finally, the reduction in fuel cycle emissions for the sum of ozone precursors (NMOG and NOx) is presented graphically in Figure G-1 and Figure G-2 for California and the South Coast Air Basin, respectively. For California, the ozone precursor reduction due to the California program reaches a maximum of 1.4 to 2.0 tpd in 2023. Comparatively, the South Coast reduction in fuel cycle emissions is estimated to range from 0.5 to 0.7 tpd by 2023.

Table G-5. California Statewide Fuel Cycle Emissions Reduction (Tons/Day) Due to the California Program, Low-End and High-End Values

Calendar Year	NMOG		NOX		CO		PM	
	Low	High	Low	High	Low	High	Low	High
2009	0.017	0.022	0.001	0.004	0.001	0.001	0.0000	0.0001
2010	0.049	0.064	0.003	0.010	0.002	0.003	0.0001	0.0002
2011	0.085	0.110	0.004	0.018	0.003	0.005	0.0001	0.0004
2012	0.125	0.162	0.007	0.027	0.004	0.007	0.0002	0.0006
2013	0.197	0.255	0.010	0.042	0.006	0.011	0.0003	0.0010
2014	0.293	0.382	0.015	0.063	0.009	0.016	0.0005	0.0014
2015	0.414	0.539	0.022	0.089	0.013	0.023	0.0007	0.0020
2016	0.545	0.715	0.029	0.117	0.017	0.030	0.0009	0.0027
2017	0.669	0.878	0.035	0.144	0.021	0.037	0.0011	0.0033
2018	0.789	1.035	0.042	0.170	0.025	0.044	0.0012	0.0039
2019	0.902	1.184	0.047	0.195	0.028	0.050	0.0014	0.0044
2020	1.011	1.327	0.053	0.218	0.032	0.056	0.0016	0.0050
2021	1.111	1.468	0.058	0.241	0.035	0.062	0.0018	0.0055
2022	1.208	1.595	0.064	0.262	0.038	0.067	0.0019	0.0060
2023	1.300	1.718	0.068	0.282	0.041	0.073	0.0021	0.0065

Table G-6. South Coast Air Basin Fuel Cycle Emissions Reduction (Tons/Day) Due to the California Program, Low-End and High-End Values

Calendar Year	NMOG		NOX		CO		PM	
	Low	High	Low	High	Low	High	Low	High
2009	0.007	0.010	0.000	0.002	0.000	0.000	0.0000	0.0000
2010	0.020	0.027	0.001	0.004	0.001	0.001	0.0000	0.0001
2011	0.034	0.045	0.002	0.007	0.001	0.002	0.0001	0.0002
2012	0.049	0.065	0.003	0.011	0.002	0.003	0.0001	0.0002
2013	0.077	0.101	0.004	0.017	0.002	0.004	0.0001	0.0004
2014	0.112	0.148	0.006	0.024	0.004	0.006	0.0002	0.0006
2015	0.157	0.207	0.008	0.034	0.005	0.009	0.0002	0.0008
2016	0.204	0.272	0.011	0.045	0.006	0.011	0.0003	0.0010
2017	0.250	0.332	0.013	0.055	0.008	0.014	0.0004	0.0012

2018	0.294	0.391	0.015	0.064	0.009	0.017	0.0005	0.0015
2019	0.336	0.448	0.018	0.074	0.011	0.019	0.0005	0.0017
2020	0.376	0.502	0.020	0.082	0.012	0.021	0.0006	0.0019
2021	0.412	0.552	0.022	0.091	0.013	0.023	0.0006	0.0021
2022	0.446	0.598	0.023	0.098	0.014	0.025	0.0007	0.0022
2023	0.479	0.642	0.025	0.106	0.015	0.027	0.0008	0.0024

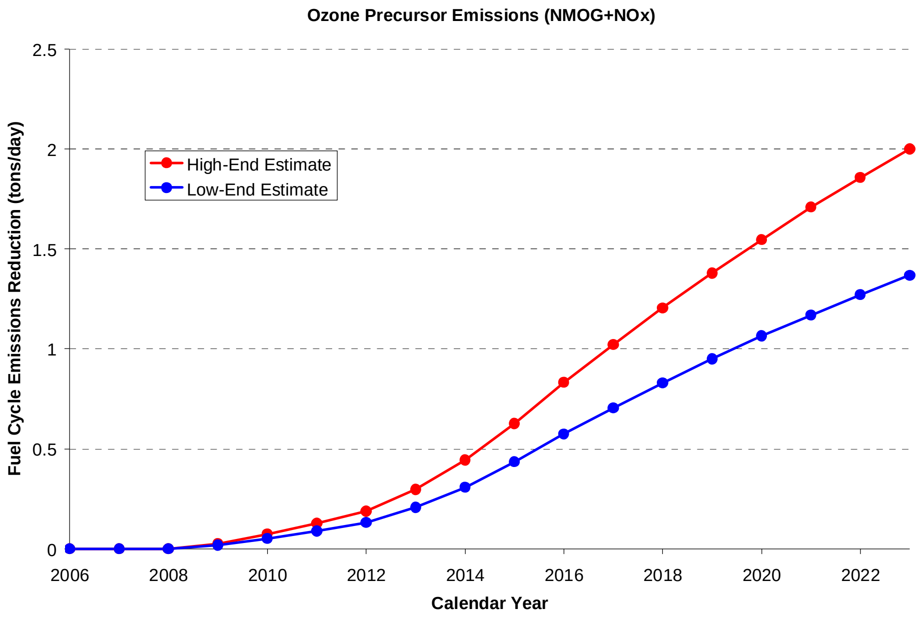

Figure G-1. Reduction in Summer Season California Fuel Cycle Emissions Due to the California Program (California Statewide)

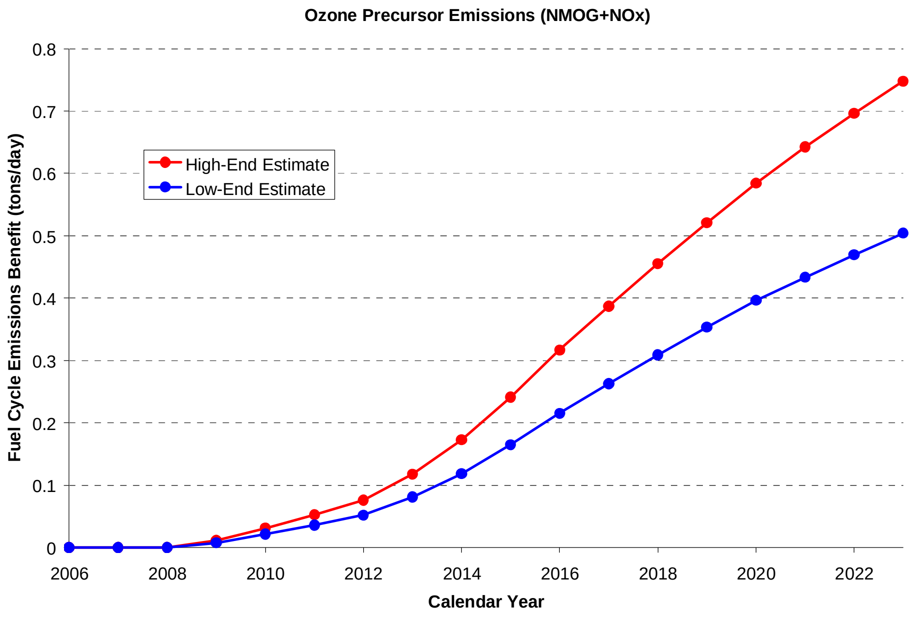

Figure G-2. Reduction in Summer Season California Fuel Cycle Emissions Due to the California Program (South Coast Air Basin)

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