PUBLIC POLICY INSTITUTE OF CALIFORNIA

Climate Change Challenges

Vehicle Emissions and Public Health in California

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March 2010

Funded in part by a grant from The California Wellness Foundation

Summary

Two of California's greatest environmental challenges are to meet national ambient air quality standards and to reduce greenhouse gas emissions that cause global warming. Although California has been struggling with air quality problems for more than four decades, concern over climate change is a relatively new phenomenon. Yet, the common ground between these two concerns is evident—both air quality and climate change policies aim to reduce the harmful pollutants that threaten the public's health and well-being. And one of the major culprits in both cases is the same—motor vehicles, the leading source of both smog-forming and greenhouse gas emissions.

This study examines options for reducing emissions from motor vehicles and evaluates each of the options in terms of its public health, climate change, and cost implications, including the uncertainty associated with each option. We examine battery-electric vehicles, fuel cell vehicles, the use of ethanol blends in flex-fuel vehicles, and reductions in vehicle miles traveled. We find that increasing the use of battery-electric vehicles provides the greatest public health benefit per unit of GHG emission reduction, followed closely by the use of fuel cell vehicles, and then by reductions in vehicle miles traveled. However, all of these options involve tradeoffs, and none ranks favorably along all dimensions. For example, battery-electric and fuel cell vehicles provide significant public health and climate change benefits, but both options involve high cost and uncertainty. Flex fuel vehicles consuming fuel blends containing ethanol derived from corn, on the other hand, have fairly low technological uncertainty, but do not provide any significant public health or climate change benefit.

Looking ahead, California needs to design policies that will reduce emissions from the transportation sector at a reasonable cost, while achieving maximum benefits for both public health and the climate. Policymakers, industry leaders, and the public need to understand the tradeoffs among these goals and seek to reconcile them. For example, there is still considerable uncertainty surrounding battery-electric and fuel cell vehicles, which will depend on technological breakthroughs and broader market penetration to reduce cost and meet performance targets. And while biofuels may help reduce global warming, their benefits will be greatly reduced if future policies are not also designed to account for their impacts on land use and their potentially adverse effect on food prices, depending upon the material used in their production.

In the concluding sections of this paper, we discuss California's policy goals relating to air quality and climate change and the role of the transportation sector in meeting these goals. We also evaluate some of the policy options that California is likely to consider in terms of their climate benefits, public health impacts, and cost.

Contents

All technical appendices to this paper are available on the PPIC website:
http://www.ppic.org/content/pubs/other/310LBR_appendix.pdf

Tables

Figures

Abbreviations

AB	Assembly Bill
BEV	Battery-Electric Vehicle
CARB	California Air Resources Board
CARFG	California Reformulated Gasoline
CEC	California Energy Commission
CO_2	Carbon Dioxide
CO_2-eq	Carbon Dioxide Equivalents
EMFAC	EMission FACtors model
EPA	Environmental Protection Agency
FCV	Fuel Cell Vehicle
FFV	Flex-Fuel Vehicle
GHG	Greenhouse Gas
GMERP	Goods Movement Emission Reduction Plan
HD	Heavy Duty
HDV	Heavy-Duty Vehicle
LCFS	Low-Carbon Fuel Standard
MMT	Million Metric Tons
MPO	Metropolitan Planning Organization
NOx	Oxides of Nitrogen
PM	Particulate Matter
ROG	Reactive Organic Gases
SACOG	Sacramento Area Council of Governments
SB	Senate Bill
VMT	Vehicle Miles Traveled
WTW	Well to Wheel
ZEV	Zero-Emissions Vehicle

Introduction

In 1943, the first recognized smog episodes occurred in Los Angeles. Visibility declined to about three blocks, and people suffered acute effects such as burning eyes, nausea, and respiratory discomfort.[1] In 1973, the earliest year records are available, the South Coast Air Basin, which includes Los Angeles, violated the current federal eight-hour ozone standard on 174 days (followed by over a decade in which the standard was violated over 200 times a year in nearly every year).[2] While some progress is being made, California continues to face severe air quality challenges. In 2008, the South Coast violated the federal ozone standard on 140 days, and the San Joaquin Valley violated the standard on 127 days.

Cars and trucks have received a significant amount of attention in the state's efforts to address air quality problems. California has been actively seeking to reduce the environmental impact of automobiles since the 1960s, establishing the nation's first automobile emissions standard in 1964 to limit emissions of oxides of nitrogen (NOx) and carbon monoxide from passenger cars beginning in model year 1966. In recognition of California's leadership in this area and the state's extraordinary air quality challenges, the federal Clean Air Act Amendments of 1967 included a provision allowing California to establish its own, more-stringent vehicle emissions standards. This provision stands today—as do the air quality challenges facing the state: Nine of the 10 counties with the worst ozone air quality in the nation are in California (American Lung Association 2009).

While California still faces some of the nation's worst air quality problems and public health remains a priority, other environmental concerns have also come to the fore, presenting the state's policymakers with the complex task of improving air quality, minimizing contributions to global warming, and reducing dependence on petroleum. This tripartite challenge has resulted in a number of regulatory efforts and policies aimed at reducing emissions and energy consumption in the transportation sector, the state's largest source of smog-forming and GHG emissions. For example, in its recent report describing a state alternative fuels investment plan, the California Energy Commission (CEC) listed five key policy objectives: Reduce GHG emissions, reduce petroleum use, increase alternative fuel use, increase in-state biofuel use, increase in-state biofuel production (California Energy Commission 2009).

The ways in which California meets its three primary goals—improving air quality and public health, reducing the risks associated with global warming, and gaining greater energy independence for the state through alternative fuels—can be mutually reinforcing, or they can be in conflict. For example, increasing the use of alternative fuels can lessen petroleum use and, depending on the fuel, reduce GHG emissions and improve public health. But some alternative fuels can actually increase GHG emissions, and some biofuels can harm public health.

[1] California Air Resources Board: http://www.arb.ca.gov/html/brochure/history.htm.

[2] The number of violations is calculated based on today's federal ozone standard, set by the Environmental Protection Agency. The standard was changed from a one hour averaging time to the current eight-hour average in 1996. The ozone standard was most recently updated in 2008, and the EPA proposed another revision to further strengthen the standard in January 2010.

Table 1 lists current laws and regulations related to air quality, climate change, and petroleum reduction that affect the transportation sector in California. In addition to the state's own laws and regulations, several recent decisions by the Environmental Protection Agency are likely to result in federal regulations governing GHG emissions.[3]

The paper focuses primarily on the light-duty transportation sector (i.e., passenger vehicles) but also includes some discussion of the heavy-duty sector (i.e., trucks and buses). Because of the significant emissions from the heavy-duty sector, it is likely to be an area that offers opportunities for solutions that are beneficial for climate change as well as public health (Bailey et al., 2008). The next section discusses the state's policy goals related to air quality and climate change, and the role of transportation in meeting them. Sections 3 and 4 describe the policy framework for reducing transportation's environmental footprint and the technology and policy approaches available to make this happen. Section 5 evaluates the likely effects of various policy alternatives on climate change, public health, and cost. We then conclude with a discussion of tradeoffs and how the foregoing analysis can inform policy choices. A technical appendix describes our data and methods.

[3] In December 2009, the Administrator of the Environmental Protection Agency took the first steps necessary for regulating GHG emissions under the Clean Air Act. The agency stated that greenhouse gas emissions are a danger to public health and that GHG emissions from motor vehicles contribute to the GHG emissions that pose a threat to human health, thus formally enabline the agency to develop GHG regulations for new passenger vehicles and paving the way for further regulation of GHG emissions under the Clean Air Act. More information is available at http://www.epa.gov/climatechange/endangerment.html.

TABLE 1
Environmental laws and regulations affecting transportation in California

Goal	Laws/Regulations	Description
Air quality	National Ambient Air Quality Standards	Sets standards for six principal or “criteria” pollutants (carbon monoxide, lead, nitrogen dioxide, particulate matter, ozone, and sulphur dioxide). Regions of the state must attain the air quality standard for ozone (most recently updated in 2008) and the standard for particulate matter (most recently updated in 2006). A more stringent standard for ozone was proposed in January 2010.
Climate change	AB 1493: Passenger vehicle GHG standards	Law adopted in 2002, standards adopted in 2005: Achieve maximum feasible, cost-effective reduction of GHG emissions from new passenger vehicles.
	AB 32: Global Warming Solutions Act	Passed in 2006. Requires the state to reduce GHG emissions to 1990 levels by 2020.
	Low Carbon Fuel Standard	Adopted as part of AB 32 implementation. Goal is to reduce carbon intensity of transportation fuels 10% below current levels by 2020.
	SB 375: Regional GHG emission reduction targets	Law adopted in 2008 as part of AB 32 implementation. Requires regions to reduce GHG emissions from vehicles through reductions in vehicle miles traveled (VMT).
Petroleum reduction	AB 2076	Passed in 2000. Calls for the development of a plan to reduce petroleum use in the state. Plan adopted by California Energy Commission and California Air Resources Board to reduce petroleum use 15% below 2003 levels by 2020 and to increase use of alternative fuels to 20% of on-road demand by 2020 and 30% by 2030.
	AB 1007	Passed in 2005. Directs California Energy Commission to develop a plan to increase the use of alternative fuels. Plan completed in 2007.
	Bioenergy action plan	Executive order signed in April 2006 to increase in-state production of biofuels 20% by 2010, 40% by 2020, 75% by 2050.
	AB 118	Law passed in 2007 (amended in 2008). Directs California Energy Commission to develop and deploy alternative fuels and advanced vehicle technology. Program provides $120 million annual incentives.

NOTES: AB 32 requires economy-wide reductions in GHG emissions. The Low Carbon Fuel Standard and SB 375 emission standards are two components of the plan, specifying ways to meet the AB 32 emissions target.

California's Environmental Goals

California faces significant environmental challenges and has established ambitious goals to address these challenges, including efforts to improve air quality, reduce the emissions that cause global warming, reduce petroleum consumption, and promote clean energy. While many of the policies supporting these efforts are designed to address a single goal, they are likely to have important links to one another, particularly in the context of the transportation sector, as we discuss below.

Improving Air Quality

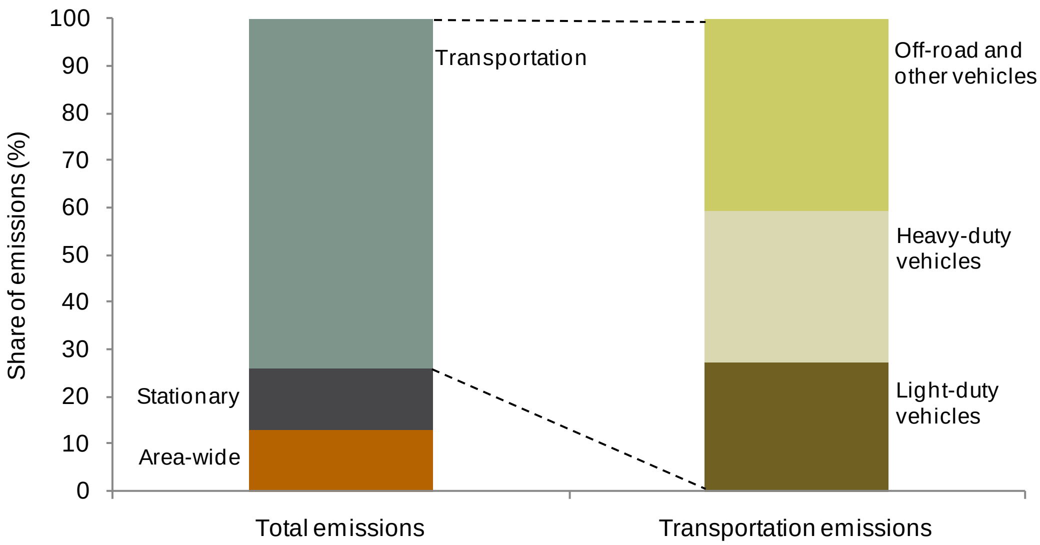
Air quality in California ranks among the worst in the nation (American Lung Association 2009). The Environmental Protection Agency (EPA) sets standards for six "criteria" air pollutants: ozone, particulate matter, nitrogen dioxide, sulfur dioxide, lead, and carbon monoxide. Among the six, ozone and particulate matter pose the most widespread air quality problems. Over eighty percent of the people in California live in an area that is out of attainment with one of the federal air quality standards (EPA 2009a).

Poor air quality contributes to increased rates of respiratory and cardiovascular disease. Exposures to high levels of ozone are associated with aggravation of respiratory ailments, restrictions in activity, increased hospitalizations, and premature mortality (Ostro, Tran, and Levy, 2006). Ozone exposure has also been linked to the development of asthma in children (McConnell et al., 2002). Particulate matter—small particles and liquids in the air, including acids, metals, organic compounds, and dust—can penetrate the lungs and aggravate existing conditions (such as asthma), cause respiratory irritation, and decrease lung function. It has also been linked to premature death in people with heart and lung disease (American Lung Association, 2009).

Smog-forming emissions include oxides of nitrogen (NOx) and reactive organic gases (ROG), which react in the presence of sunlight to form ozone. NOx emissions also contribute to the formation of particulate matter. The transportation sector—which accounts for approximately three-quarters of smog-forming emissions in California—is of significant concern in the state's efforts to meet air quality standards. About one-quarter of the emissions in the transportation sector are generated by light-duty vehicles, about one-third by heavy-duty vehicles, and the remainder by off-road vehicles (Figure 1).[4] Heavy-duty vehicles and off-road vehicles used in goods movement are the largest sources of pollution targeted for emission reduction in the state's plan to attain the federal eight-hour ozone standard in the South Coast and the San Joaquin Valley. After the transportation sector, the major sources of smog-forming pollutants are ROG emissions from consumer products (e.g., aerosols) and farming operations (i.e., raising animals) and NOx emissions from manufacturing and industrial sources.

[4] Calculations based on data from CARB. Off-road sources include construction equipment, farm equipment, ships, trains, and planes.

FIGURE 1
Sources of smog-forming emissions in California, 2006

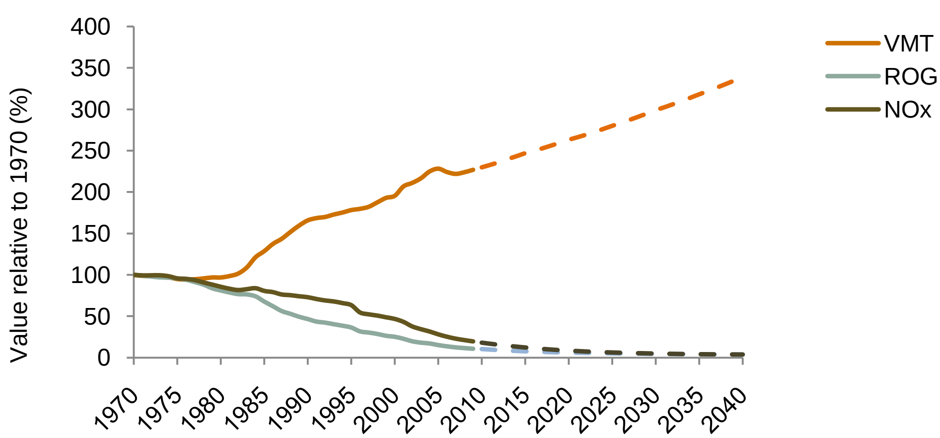


SOURCE: California Air Resources Board (www.arb.ca.gov/ei/ei.htm).

NOTE: Total emissions include oxides of nitrogen and reactive organic gas emissions.

California has been quite successful in reducing emissions that contribute to poor air quality, particularly from passenger vehicles. As Figure 2 shows, even as vehicle miles travelled have increased, smog-forming emissions from passenger vehicles have declined (and are projected to continue declining over the next thirty years). These reductions are attributable to increasingly stringent emission standards for new passenger vehicles, better vehicle maintenance, and new fuel formulations. California has been establishing regulations to reduce emissions from passenger vehicles since the 1960s and has been given special authority under the federal Clean Air Act to continue to set its own standards, as long as they are no less stringent than those established by the federal government. California's policies have not only been adopted by other states but have also served as a model for the federal government (National Research Council, 2006).

FIGURE 2
Passenger vehicle emissions and miles traveled

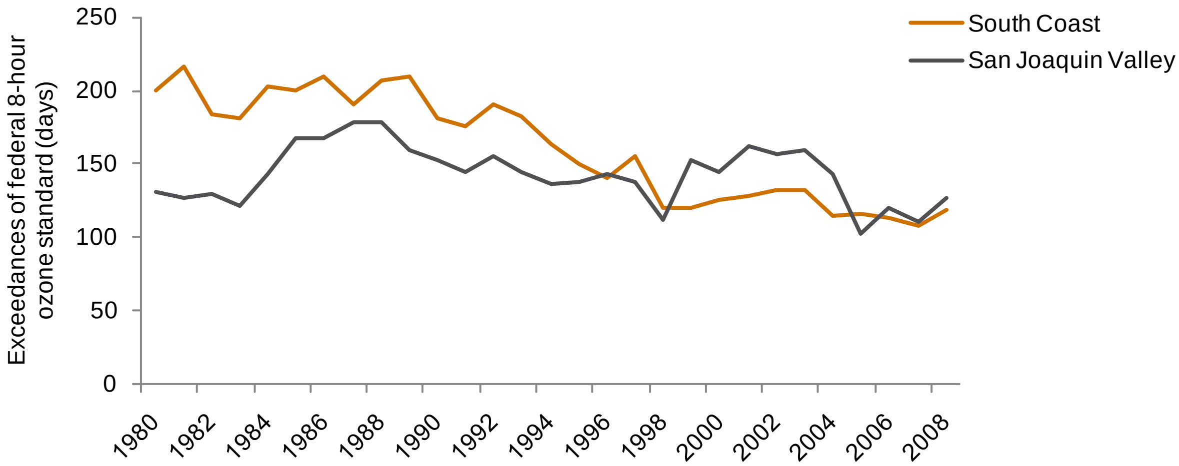


SOURCE: Output from EMFAC (see California Air Resources Board 2006a).

NOTE: Dotted lines are projections. Projections do not include implementation of GHG emission standards for new passenger vehicles or Low-Carbon Fuel Standard.

Despite these reductions in vehicle emissions, the state still has a long way to go in achieving clean air standards. This is particularly true for the South Coast and San Joaquin Valley air basins. Although both basins have made progress in reducing the number of days they exceed the federal ozone standard, both still violate the standard more than 100 days every year (Figure 3); and under the more restrictive standards proposed in January 2010, the number of violations will increase, and even more areas of the state will fall out of compliance with air quality standards.

FIGURE 3
Violations of federal eight-hour ozone standard, South Coast and San Joaquin Valley air basins



SOURCE: California Air Resources Board (www.arb.ca.gov/adam/php_files/aqdphp/trends1.php).

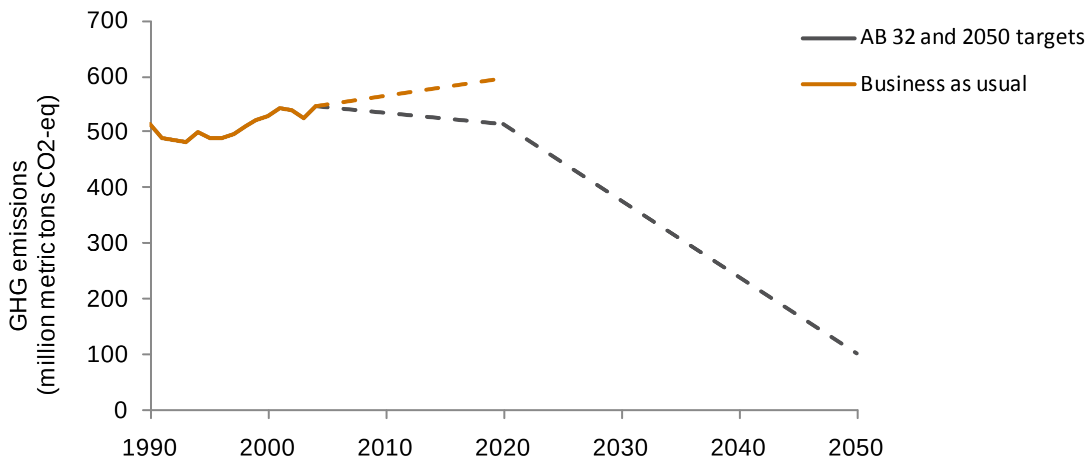
Reducing Greenhouse Gases

Climate change resulting from heat-trapping gases will present significant challenges for California, including risks to the state's water supply and other resources. Global warming will also increase the frequency of extreme events such as heat waves and wildfires, posing risks to human health and infrastructure (Hayhoe et al., 2004; Luers et al., 2006; Cayan et al., 2008; Franco et al., 2008; Mastrandrea et al., 2009; Moser et al., 2009). A changing climate will also make it more difficult to meet air quality standards (Steiner et al., 2006; Bedsworth, 2008; Millstein and Harley, 2009). Higher temperatures increase the chemical formation of ozone, as well as emissions from natural sources such as plants. Higher temperatures also increase the demand for air conditioning, resulting in the generation of additional electricity and smog-forming emissions. The likelihood of more frequent wildfires also poses a risk for air quality. In sum, global warming will increase the difficulty of controlling smog-forming emissions and meeting air quality standards (Steiner et al., 2006; Millstein and Harley, 2009).

California began assessing global warming in the late 1980s, when the California Energy Commission was directed to undertake its first assessment of the impacts of climate change on California (Franco et al., 2008). In 2002, California took its first step toward reducing GHG emissions, passing AB 1493, which required CARB to establish GHG emission standards for new passenger vehicles (see regulations and standards listed in Table 1). These standards, when implemented, require a 30 percent reduction in GHG emissions from the new light-duty vehicle fleet by 2016.

In 2005, Governor Schwarzenegger signed Executive Order S-03-05, which calls for significant reductions in statewide GHG emissions—reductions to 1990 levels by 2020, and reductions to 80 percent below 1990 levels by 2050 (Figure 4). The latter goal is the level believed to be necessary on the part of industrialized nations as a whole to achieve climate stabilization. In 2006, the state adopted AB 32, which codifies into law the 2020 emission reduction target for the state. While the state has not codified the 2050 reduction target into law, the programs being implemented to achieve the 2020 target are doing so with an eye toward the 2050 target (California Air Resources Board, 2008b).

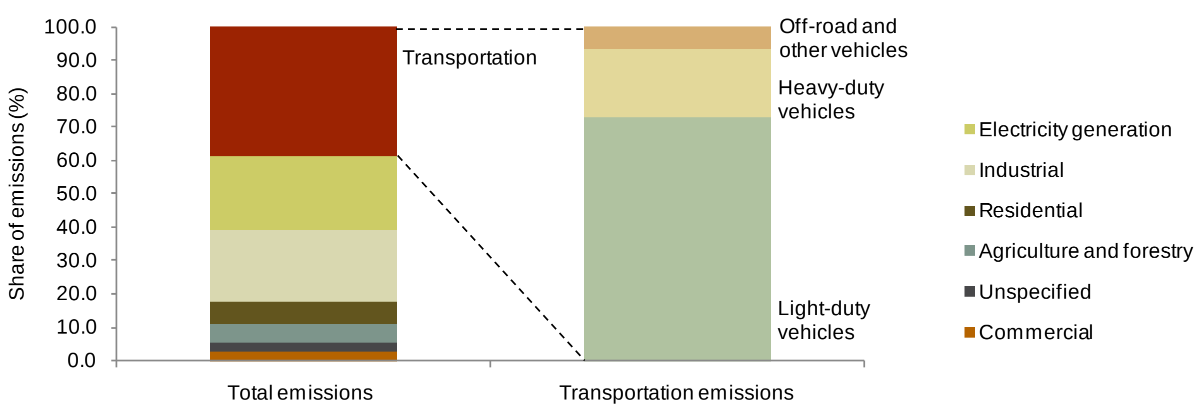
FIGURE 4
California's economy-wide GHG emission reduction targets



SOURCE: California Air Resources Board.

Transportation is not only the largest source of smog-forming emissions in California, as shown in Figure 1, but also the largest source of GHG emissions (Figure 5). Electricity generation represents the next largest source of emissions after transportation, followed by the industrial sector (dominated by the manufacturing, cement, and refining industries).

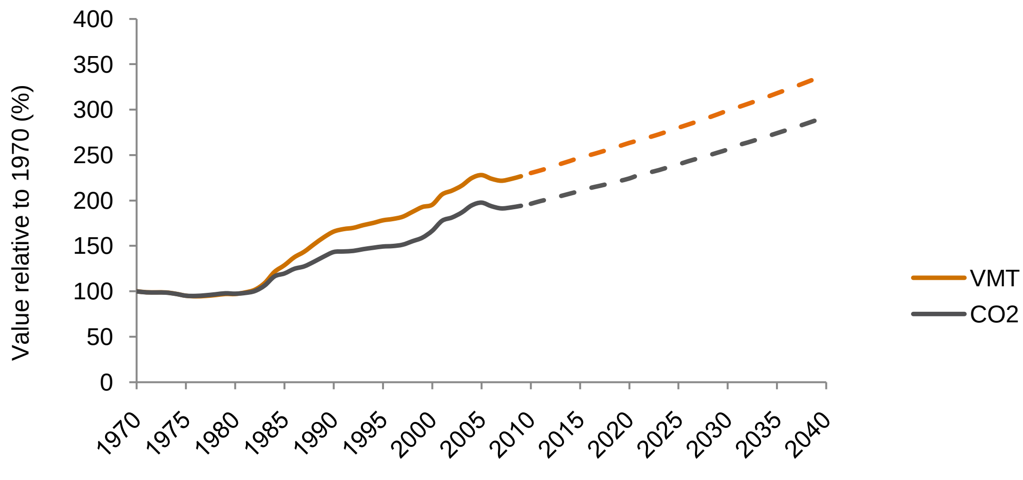
FIGURE 5
Greenhouse gas emissions in California, 2006



SOURCE: California Air Resources Board (www.arb.ca.gov/cc/inventory/inventory.htm).

However, the story is slightly different in the case of GHG emissions. While there have been significant efforts to reduce smog-forming emissions from passenger vehicles, until recently there have been no corresponding standards established for GHG emissions—and these emissions have continued to rise (Figure 6).

FIGURE 6
Passenger vehicle carbon dioxide emissions and miles traveled



SOURCE: Output from EMFAC (see California Air Resources Board 2006a).

NOTE: Dotted lines are projections. Projections do not include implementation of GHG emission standards for new passenger vehicles or Low-Carbon Fuel Standard.

In addition, over the past several decades, federal fuel economy standards have not changed, and shifts in the composition of the vehicle fleet (i.e., an increasing share of sport utility vehicles and pick-up trucks) led to an overall decline in fleet-average fuel economy between the late 1980s and 2004. Beginning in 2005, fleet-average fuel economy started to slowly increase (EPA, 2008). Fuel economy is obviously a key determinant in vehicle GHG emissions, and the large percentage of light-duty vehicles on the road today continue to represent the lion's share of GHG emissions in the transportation sector. The same is true for the United States as a whole (EPA, 2009b).

With the passage of AB 1493 in 2002 (Table 1), California took its first step toward regulating vehicle carbon dioxide emissions. Subsequent litigation has upheld the state's right to establish its own new-vehicle GHG emission standards.[5] Implementation of AB 1493 is a key component in the state's plan to meet the AB 32 target (reduction in GHG statewide emissions to 1990 levels by 2020), and transportation programs represent the largest source of reductions in the AB 32 Scoping Plan (California Air Resources Board, 2008b). The Scoping Plan, adopted by CARB in December 2008, outlines how the state will achieve its 2020 emission reduction target (Table 2).

[5] For more on the law and litigation activities, see the Attorney General's website: http://ag.ca.gov/globalwarming/motorvehicle.php.

TABLE 2
AB 32 emission reduction programs

	Estimated emission reductions (MMTCO2-eq)	Share of total emission reductions
Transportation measures		**36%**
GHG emission standards for new passenger vehicles	31.7	
Low-carbon fuel standard	15	
Vehicle efficiency measures	4.5	
Goods movement	3.7	
Local government actions and regional GHG targets	5	
Heavy/medium-duty vehicles	1.4	
High-speed rail	1	
Electricity generation		**29%**
Energy efficiency	26.3	
Accelerated renewable portfolio standard (33% by 2020)	21.3	
Million solar roofs	2.1	
Industrial sources		**13%**
Industrial measures (sources under cap)	0.3	
High GWP measures	20.2	
Industrial measures (sources not covered under cap)	1.1	
Landfill methane control	1	
Sustainable forests	**5**	**3%**
Cap and trade	**34.4**	**20%**
Total emission reductions included in the AB 32 scoping plan	**174**	

SOURCE: California Air Resources Board 2008b.

NOTE: The Scoping Plan accounts for more than the 169 million metric tons of CO_2-eq needed to meet the 2020 emission reduction target.

Reducing Dependence on Petroleum

The California Legislature passed AB 2076 in 2000, directing the CEC and CARB to develop a plan for reducing the state's dependence on petroleum. One of the motivations for the legislation was to prepare for possible fuel shortages.[6] CEC presented a plan that recommended a goal of reducing petroleum consumption to a level 15 percent below 2003 levels by 2020 (California Energy Commission, 2009). Although never codified into law, this goal was adopted by CEC and CARB, and many of CEC's activities have focused on reducing petroleum dependence, including development of an alternative fuel investment strategy and a bioenergy action plan.

Reducing California's dependence on petroleum has many benefits, including a sharp reduction in smog-forming and GHG emissions. By the same token, most efforts to reduce GHG emissions in the transportation

[6] Text of the legislation is available at www.leginfo.ca.gov/pub/99-00/bill/asm/ab_2051-2100/ab_2076_bill_20000930_chaptered.html.

sector are likely to result in less consumption of petroleum. Investments in alternative energy sources will also help insulate the state from price spikes associated with the world oil market and will provide new economic opportunities within the state.

Improving Public Health

One of the primary motivations behind California's environmental efforts is a desire to improve public health. Reducing smog-forming emissions will reduce the adverse health effects associated with pollution in the local region where the reductions occur (Ostro et al., 2006). Reducing GHG emissions, on the other hand, is more dependent on global responses to the problem and will result in a broader array of positive health benefits that may not be localized. However, any concurrent reductions in smog-forming and toxic emissions that accompany efforts to reduce GHG emissions will have a direct local benefit.

Poor air quality can affect respiratory and cardiovascular health and lead to illness, and even death. CARB staff estimated that diesel particulate matter contributed to 3,500 deaths in 2005 (California Air Resources Board, 2008c). CARB estimates that there is a 10 percent increase in the risk of premature death for each 10 $\mu g/m^3$ increase in fine particulate matter (the national ambient air quality standard for fine PM is 35 $\mu g/m^3$).[7] Statewide, it is estimated that, on average, 260,000 premature deaths per year are associated with short-term exposure to ozone pollution and, among children under age 18, an average of just over 93,000 hospital admissions for respiratory disease and more than 35,000 emergency room visits for asthma (Ostro et al., 2006).[8] Another study finds that attaining the federal eight-hour ozone standard for fine particulate matter would avoid almost 1,600 new cases of adult-onset chronic bronchitis in the South Coast Air Basin and over 360 cases annually in the San Joaquin Valley (Hall et al., 2008). Improving air quality would also provide substantial economic benefits. Attaining the federal eight-hour ozone standard could save over $2.5 billion in medical costs, lost work days, and reduced mortality.[9]

Public health considerations are also an important driver in the state's efforts to reduce GHG emissions. Increasing temperatures will make it more difficult to meet state and federal air quality standards (Steiner et al., 2006), and any increase in the frequency and intensity of extreme heat events will increase morbidity and mortality (Hayhoe et al., 2004; Miller et al., 2008). In July 2006, a heat wave in California resulted in 140 deaths and more than 16,000 emergency room visits and 1,100 hospitalizations (Trent, 2007; Knowlton et al., 2008). Climate change is also expected to increase the risk of inland and coastal flooding and to alter the incidence and range of vector-borne illnesses.

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[7] In 2006 there were just over 2,500 vehicular deaths reported in the San Joaquin Valley and South Coast Air basins. In that same year, over 3,800 deaths in those regions were estimated to be related to exposure to fine particulate matter (Hall et al., 2008).
[8] The estimates are calculated from Ostro et al. (2006), using rates per thousand individuals. The rates per thousand reported in the paper are 7.68 premature deaths and, for individuals under age 18, 10.13 hospital admissions for respiratory illness and 3.81 emergency room visits for asthma.
[9] The mean value of a statistical life used by Ostro et al. (2006) is $6.5 million (89% of the benefit reported is associated with reductions in mortality).

California's Transportation Policy Framework

California has established an extensive policy framework for reducing the environmental impact of the transportation sector. This framework includes three approaches for dealing with vehicle emissions: improving vehicle technology, altering fuel formulations, and reducing the driving. The first two approaches are reflected in California's low-emission vehicle standard and reformulated gasoline regulations. The state has also sought to reduce petroleum dependence by encouraging greater vehicle efficiency and the use of non-petroleum-based fuels. More recently, the passage of SB 375 gives CARB the authority to set regional GHG emission-reduction targets, which will be met in part through reductions in vehicle miles traveled. All three of these approaches are discussed in the AB 32 Scoping Plan (California Air Resources Board, 2008b).

Improving Vehicle Technology

California has long been a leader in developing technology-forcing regulations to reduce the environmental impact of cars and trucks—as exemplified in the state's low-emission vehicle regulations. The intent of a technology-forcing regulation is to push technology beyond its current state to achieve a given standard.[10] California's low-emission vehicle program establishes emission standards for new vehicles and sets a fleet-average emission level that must be met by all large vehicle manufacturers in the state.

Another key area in California's efforts to control emissions is represented in its ZEV (zero-emission vehicle) program. The program has undergone substantial revision since its inception in 1990, but the goal remains to push the development of vehicles that have no tailpipe emissions (Bedsworth and Taylor, 2007). While originally envisioned as an air quality effort, ZEVs will also be helpful in reducing GHG emissions. In its current form, the ZEV program provides credits for the purchase of battery-electric vehicles, fuel cell vehicles, hybrid electric vehicles, plug-in hybrid electric vehicles, and extremely clean conventional vehicles. The program is expected to undergo review and likely revision again in 2010.

Vehicle GHG Emission Standards

In 2002, California passed AB 1493 (Pavley), which requires CARB to establish the first-ever GHG emission standards for new passenger vehicles. The standards were finalized in 2004 and were set to be implemented beginning with the 2009 model year (the implentation date has been delayed). The standards are expected to achieve a 30 percent reduction in GHG emissions from new passenger vehicles by 2016. These standards, and subsequent standard updates, will be met through a combination of approaches, including improvements in vehicle efficiency, shifts in vehicle technology toward electric drive and fuel cells, and greater use of alternative fuels.

[10] A well-known example is the EPA requirement in the early 1970s to reduce smog-forming emissions, which resulted in the development of the catalytic converter. BACT or "best available control technology" represents an alternative regulatory approach. BACT regulation requires that the best technology be used, but it does not directly "force" technology by setting a standard that can only be met through the development of new technology.

Improving Vehicle Fuels

The second component in California's policy framework for reducing emissions involves the reformulation of vehicle fuels. Adjustments in fuel formulation can result in fewer emissions, and the use of non-petroleum based additives—for example, ethanol (an oxygenate that promotes more complete combustion)—can result in reduced petroleum use.

The Clean Air Act Amendments of 1990 required oxygenated and reformulated gasoline to be used in areas that did not meet federal air quality standards. This requirement led California to develop standards for a reformulated gasoline (CARFG) with a higher oxygen content (among other things) that would burn more cleanly and reduce emissions. Analysis of the impact of CARFG in the San Francisco Bay Area did find a reduction in some emissions from vehicles using this fuel (Kirchstetter et al., 1996).

California has also pursued several other efforts to reduce petroleum use and GHG emissions. AB 1007, passed in 2005, required the CEC to develop a plan to increase the use of alternative fuels in California. AB 118, passed in 2007, authorized the CEC to spend roughly $120 million a year for the next seven years to "develop and deploy innovative technologies that transform California's fuel and vehicle types to help attain the state's climate change policies." The largest share of money in the funding allocation for AB 118 is directed toward the development of electric drive, natural gas, and hydrogen technologies (California Energy Commission, 2009). An additional $200 million has been provided to CARB and the Bureau of Automotive Repair (the agency responsible for the state's Smog Check program) to promote the development of new fuels, vehicles, and infrastructure through research, development, and deployment and for workforce training programs.

Most recently, in April 2009, CARB adopted the regulations needed to implement the low-carbon fuel standard (LCFS), which contains requirements to reduce the carbon intensity of transportation fuels 10 percent by 2020 (California Air Resources Board, 2009a, 2009b). Governor Schwarzenegger issued a corresponding Executive Order, S-01-07, calling for a 10 percent reduction in the carbon intensity of transportation fuels by 2020.[11] The low-carbon fuel standard is a performance standard that must be met by fuel producers and importers, but it allows for trading of low-carbon fuel credits among fuel providers.

Reducing Vehicle Miles Traveled

The third component in California's policy framework for reducing emissions focuses on limiting vehicle miles traveled. Studies have shown that the built environment can have a significant effect on overall VMT (Ewing and Cervero, 2001). An analysis of planning studies suggests that VMT could be reduced 17 percent by 2050 through the implementation of smart growth scenarios (Bartholomew and Ewing, 2009). A smart growth scenario that achieves these emission reductions is likely to focus on land use (e.g., more compact growth, infill development), investments in public transit, alternatives to single-occupant vehicle travel, and, in some cases, policies that increase the cost of driving.

California has been the site of many planning exercises. In the late 1990s, several regions in California began efforts to coordinate regional planning for transportation investments, air quality, and land use. The state formalized this effort in 2005 by providing grants and guidance through a Blueprint Planning Program in which regional agencies worked with the community to develop a preferred scenario for future growth.

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[11] Text of the executive order is available at www.arb.ca.gov/fuels/lcfs/eos0107.pdf.

In three of the state's four largest regions, the preferred scenario included smart growth policies that diverged from the current practice (Barbour and Teitz, 2006). One of the most successful efforts was completed in the Sacramento region under the guidance of the Sacramento Area Council of Governments (SACOG).[12] In their preferred scenario, SACOG projected a 26 percent reduction in VMT by 2050 relative to the current trend through different land-use practices, investments in transit and alternatives to driving, and the implementation of policies to favor this development and associated investments (SACOG 2007, updated).

The relationship between land use and vehicle miles traveled is not well represented in traditional transportation planning models. Planning exercises such as the one in the SACOG Blueprint are usually developed through a participatory visioning process and represent "one possible future outcome" (Bartholomew and Ewing, 2009). Because these visioning exercises represent an aspirational goal not fully grounded in specific policies, their estimates of VMT reduction tend to be somewhat higher than analyses that examine the actual implementation of proposed policies. However, it is also likely that modeling exercises underestimate the potential to reduce VMT through prudent land use because of technical limitations in the models' ability to gauge the relationship between land use and driving patterns (Bartholomew and Ewing, 2009).

Recently passed legislation, SB 375, attempts to build on the successes of the SACOG Blueprint planning process. SB 375 aims to link transportation and land-use planning in the state's regions in such a way as to specifically reduce GHG emissions from transportation. The law directs CARB to develop GHG emission reduction targets for California's eighteen metropolitan planning organizations (MPOs), which are responsible for regional transportation planning. Under SB375, MPOs must develop a sustainable community strategy to comply with its regional GHG emission target. The regional GHG targets will be proposed by CARB by June 2010 and adopted in September 2010. The target years will be 2020 and 2035.

In sum, California will need to employ all three of these approaches to emission reduction if it is to meet the state's air quality and climate change goals. While the focus to date has been on improving vehicle technology and fuels, the additional goal of reducing VMT will contribute a great deal to efforts seeking to not only reduce GHG and smog-forming emissions but also to reduce dependency on the primary source of the emissions, petroleum itself.

[12] See Barbour and Teitz (2006) for a discussion of the blueprint planning process in the SACOG region.

Technologies and Approaches for Reducing Transportation's Environmental Footprint

In this chapter, we discuss in greater detail the various approaches within California's policy framework that seek to redress the air quality problems generated by the transportation sector.

Vehicle Efficiency

The primary mechanism for complying with the state's GHG standards for new passenger vehicles is through improvements in vehicle efficiency that result in less fuel consumption. In the near-term, this will likely be accomplished through improvements in conventional vehicles, such as improved engines and transmissions and better vehicle aerodynamics (California Air Resources Board, 2004). Additional technologies, such as hybrid-electric vehicles, can also introduce improvements in efficiency. Such improvements can range in cost from close to zero to several thousand dollars (National Research Council, 2002; California Air Resources Board, 2004). However, because increased efficiency implies reductions in fuel use, and therefore cost savings, the improved or additional technologies may indeed "pay for themselves" over the lifetime of a vehicle.

The downside is that improvements in vehicle efficiency, and the subsequent reduction in the per-mile cost of driving, may encourage some people to drive more, reducing some of the benefits of the efficiency gains. This "rebound effect" has been observed in the case of vehicle efficiency improvements and in other energy efficiency improvements as well. Estimates of the rebound effect range from 4.5 to 25 percent (Greening, Greene, and Difiglio, 2000; Small and Van Dender, 2007). Recent analysis in California suggests that this rebound effect is smaller for the state than for the nation as a whole (Small and Van Dender, 2005).

Electric Drive

Incorporating electric drive in vehicles offers an obvious opportunity to reduce smog-forming and GHG emissions. California's zero-emission vehicle program is looking toward electric-drive vehicles—particularly battery-electric vehicles (BEVs) and fuel cell vehicles (FCVs), which do not involve a combustion engine—as a way to completely eliminate tailpipe emissions. Given the state's relatively clean generation of electricity, the bottom-line emissions of a BEV are vastly less than those of a comparable gasoline vehicle.

However, even though the zero-emission vehicle program has been in existence for more than twenty years, achieving the benefits envisioned for BEVs has proven difficult. The vehicles and enabling technologies have failed to meet cost and performance targets, reducing their market viability (Bedsworth and Taylor, 2007). The most recent review of the ZEV program concludes that BEVs are not likely to be available at commercial volumes (10,000 vehicles per year) until the middle of the next decade (Kalhammer et al., 2007). The incremental cost of a BEV remains quite high, particularly at low-production volumes, and the vehicle is still not meeting performance targets—for example, delivering a satisfactory driving range and time before recharging the battery (Kalhammer et al., 2007). The CEC has estimated that a BEV would cost $8,000 to $15,000 more than an average conventional vehicle (California Energy Commission, 2009).

As BEVs have failed to achieve their cost and performance targets, hybrid-electric vehicles have emerged as an alternative means for complying with the ZEV mandate. Since hybrid electric vehicles combine electric drive with a combustion engine, they still generate tailpipe emissions, but they usually consume less fuel than comparable gasoline vehicles. Several hybrid-electric vehicles are currently available on the market, none of which require being plugged in to charge the battery.[13] Plug-in hybrid electric vehicles, which will probably be available in several years, will provide some "all-electric" driving range (on the order to 10–15 miles) as well as the combination electric-gasoline power of a traditional hybrid. They will thus provide a way to gain some of the benefits of a battery-electric vehicle while offering the range and refueling convenience of a more traditional vehicle.

Hydrogen and Fuel Cells

Fuel cell vehicles are electric drive vehicles, but rather than deriving electricity from the grid and storing it in a battery, the electricity is produced on-board by a fuel cell. A fuel cell can be powered by a number of different fuel options, but the most common is hydrogen. A hydrogen fuel cell vehicle includes a fuel cell stack and on-board hydrogen storage, usually in a compressed form. Hydrogen can be produced from a number of feedstocks, or raw materials, most commonly natural gas. While there are emissions associated with the production of the hydrogen used to fuel the vehicle, there are no smog-forming or GHG emissions from the operation of the vehicle.

The current version of the ZEV mandate contains a compliance option based on the sale of fuel cell vehicles. Several automakers have demonstration vehicles on the road, but none are commercially available. Recent analysis for the ZEV review indicated that fuel cell vehicles are probably still a decade away from being produced at commercial volumes (Kalhammer et al., 2007).

Biofuels

Another innovation being tested in the current vehicle fleet and expected to be expanded in the future is biofuel. Biofuels are fuels derived from organic matter (e.g., corn, soybeans, or sugarcane). The biofuel most likely to be widely used in the light-duty sector is ethanol, an alcohol generally derived from corn that is blended into gasoline as an oxygenate to help the fuel burn more completely and thereby reduce smog-forming emissions (in California the current blend is about 6 percent ethanol, but this will increase to 10 percent over the next few years, as part of the state and federal efforts to increase the use of renewable fuels).[14]

Ethanol can be blended into gasoline at higher volumes for flex-fuel vehicles (FFVs). FFVs can run on gasoline or E85—a fuel blend that is 15 percent gasoline and 85 percent ethanol—or any mixture of the two. There are currently about 400,000 FFVs registered in California, although E85 is not readily available, and so most run on gasoline. Only 13 stations in California supply E85 (California Energy Commission 2009). The incremental cost of producing vehicles that can use E85 is actually quite small. Today's gasoline vehicles can be fixed in the manufacturing stage to run on E85 for about $150 per vehicle (California Energy Commission 2009). However, retrofitting gasoline stations so that they are able to dispense E85 costs between $100,000 and $250,000 per station (California Energy Commission 2009).

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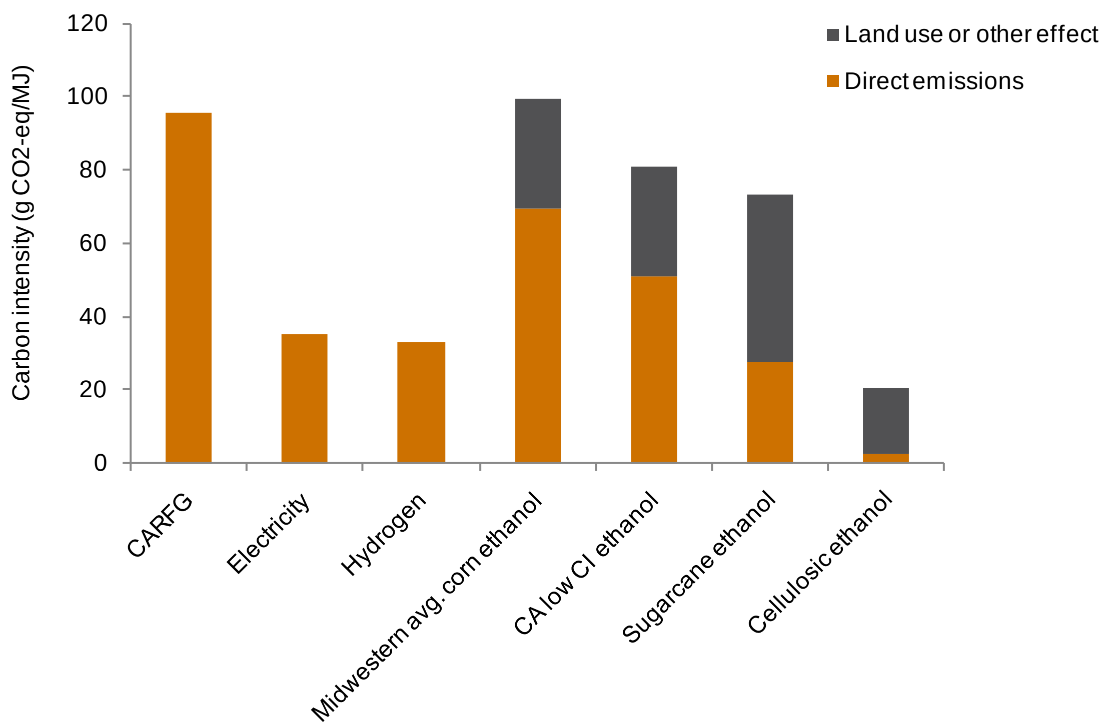
[13] None of the hybrid electric vehicles currently available include a plug-in option. Third party retrofits are available, but they are expensive and void the vehicle warranty.
[14] The EPA recently announced that it will consider increasing the allowable level of ethanol blended into gasoline to increase to 15 percent. The agency will consider this issue in 2010.

Determining the full lifecycle GHG emissions resulting from ethanol can be complex. In addition to fuel combustion, one must also consider the inputs to crop production—harvesting, transport, and conversion of the crop. To date, Brazil is the largest producer of ethanol for domestic and export markets, relying mostly on sugarcane for its production base. (The majority of ethanol consumed in the United States is derived from corn.) Ethanol produced from sugarcane has a lower carbon intensity than the ethanol derived from corn (Figure 7). However, corn appears to require less production energy (Wang, Saricks, and Santini, 1999; De Oliveira,Vaughan, and Rykiel, 2005; Farrell et al., 2006). These calculations do not include the impact of biofuels on land use, which is discussed below.

FIGURE 7
Direct and indirect GHG emissions from alternative fuel sources



SOURCE: California Air Resources Board 2009a, Table VI–3.

NOTE: Emissions are for pure fuel types only, not blends. CARFG = California reformulated gasoline. Carbon intensity for electricity and hydrogen has been adjusted to account for the improved efficiency of the vehicles. California low carbon intensity (CI) ethanol is ethanol produced in California using the latest generation ethanol production plants.

Looking to the future, much larger GHG reduction benefits can be gained by using ethanol derived from alternative feedstocks, including woody biomass, municipal solid waste, or crop residues (Wang, Saricks, and Santini, 1999; Kalogo et al., 2006; Hill et al., 2009; Williams et al., 2009). Overall, ethanol from these alternative feedstocks results in lower GHG emission than ethanol derived from corn. These reductions can occur for a variety of reasons, including the diversion of waste streams, less use of pesticides and fertilizers, less energy-intensive harvesting practices, or less-intensive tillage practices (Williams et al., 2009).

An additional consideration is the impact of biofuel production on land use. Increasing demand for biofuels can result in the conversion of undeveloped land to cropland. Soils and plant biomass serve as important reservoirs for carbon storage, and converting undeveloped land to cropland can release substantial amounts of CO_2 (Fargione et al., 2008; Searchinger et al., 2008). Figure 7 shows the lifecycle carbon intensities for a number of different vehicle biofuels, including the indirect land-use emissions for each. As the figure shows, the indirect emissions associated with various biofuels can be quite large. Although this is an emerging area of research, CARB has decided to include indirect emissions in its evaluation of biofuels in the implementation of the LCFS. Figure 7 shows the values CARB is currently assuming for each fuel, but the agency acknowledges that they are subject to modification as more information emerges.

Another concern with the increased use of biofuels is the potential impact on crops grown for food. If demand for biofuels increases, farmers might divert cropland currently being used for food to cropland for fuel. This land conversion might not only release stored carbon dioxide into the atmosphere (as discussed above) but also lead to higher food prices (Searchinger et al., 2008; Tilman et al., 2009). The potential impact could be minimized by developing biofuels from feedstocks that do not compete with food crops—for example, deriving biofuels from municipal solid waste or forestry and crop residues (Tilman et al., 2009).

Land Use, Pricing, and Transit Investments

Reducing vehicle miles traveled is also an important way to reduce emissions from the transportation sector. Reductions in VMT can be achieved through changes in land use, pricing policies that increase the cost of driving, and through investments in alternatives to driving, notably transit. Reductions in VMT are complementary to each of the other approaches to reducing vehicle emissions and are being pursued by California in conjunction with efforts to improve vehicles and fuels. A review of potential VMT reductions through different policy avenues was prepared for the California Air Resources Board (Rodier, 2009), and we discuss the results of this review below. The estimates of potential reductions in VMT, based largely on modeling, vary widely. The variation stems from the extent of changes in land use and the extent to which other tools to reduce VMT (for example, transit investment) are included. Local characteristics also affect estimates of potential VMT reduction, including future rates of growth and the development and availability of land and jobs.

Of the strategies to reduce VMT, change in land use is likely to take the longest to have an effect, emerging over several decades as new building and development occurs. Various modeling studies have estimated the impact that increasing density and diversity of land use (e.g., mixed-use development) and improving community design can have on vehicle miles traveled. A review of modeling studies from around the United States and other countries (Rodier, 2009) estimates that the median reduction in VMT from land-use changes, alone, ranges from 0.5 percent (over a 10-year time horizon) to 1.7 percent (over a 40-year time horizon). Because current transportation planning models are particularly poor at representing the relationship between land use and VMT, it is likely that these are conservative estimates of the potential for land use to reduce VMT (Bartholomew and Ewing, 2009).

Transportation pricing strategies are likely to have a more rapid and larger effect on VMT than land-use changes. Such strategies are currently coming into play in the state's larger metropolitan regions. The San Francisco Bay Area is exploring the implementation of high occupancy toll lanes. Policies such as congestion pricing, parking pricing, or pay-as-you-drive insurance can increase the cost of driving and lead people to seek alternative means of transportation. Modeling studies show a large range in the potential VMT reduction from pricing policies. Cordon, congestion, and parking pricing policies generally show about a 2 to 3 percent reduction in VMT, while modeled VMT reduction from pricing and fuel taxes ranges from about 8 to almost 16 percent (Rodier, 2009).

Another way to reduce VMT is to invest in transit systems. This can range from the construction of new rail systems to investment in rapid bus transit and dedicated bus lanes. Transit investments can provide new alternatives to automobile travel or improve the efficiency of existing transit networks. Rodier's review (2009) finds that transit investments can reduce VMT by 0.1 to 1.1 percent over 10 years and up to 3.5 percent over 40 years. The range in the estimates stems from how large the transit investment is, the state of the existing system, and the timeframe over which the investment occurs.

To achieve the greatest reductions in VMT, a region should probably combine land-use policies, pricing strategies, and transit investments. Sacramento's regional Blueprint planning process explores such combined strategies. The Blueprint scenario builds upon several "smart growth" principles, including access to transportation choices, the use of existing structures, mixed use, and compact development. This land-use strategy is coupled with policies to encourage growth through reinvestment and infill and policies to promote the development and use of transit. Under this scenario, SACOG modeling estimates that VMT per capita would decline almost 17 percent from current levels by 2050 (26 percent below projected business-as-usual levels for 2050). In addition to reducing VMT, the preferred scenario results in less additional urbanized land and less conversion of agricultural land (SACOG, 2007).

Table 3 shows the median VMT reductions for the land-use-only and combined-policies scenarios included in the review by Rodier (2009). The table also shows the range of reductions estimated in the studies. The range is attributable to the aggressiveness of the land-use policies, the size and growth rate of the region, and the state of the existing transit system. As reflected in the table, the combined-policies scenario achieves much higher VMT reductions in both the near- and long-term.

TABLE 3
VMT reduction scenarios

Time horizon	10 years	20 years	30 years	40 years
	Reduction in VMT per capita relative to business as usual (%)			
Land use only (n = 19)	0.5 (0 – 3.1)	1.1 (0.1 – 6)	1.4 (0.1 – 7.5)	1.7 (0.2 – 9.8)
Land use, transit investment, and pricing (n = 15)	14.5 (4.9 – 33)	18.0 (8.8 – 52)	21.4 (12.9 – 70)	24.1 (12.7 – 79.9)

SOURCE: Rodier 2009.

NOTE: "n" indicates the number of studies evaluated, and the range shown is the 95% confidence interval for the analyses.

Uncertainties

Achieving emission reductions in the transportation sector involves a number of uncertainties. The first pertains to the cost and performance of new technologies and fuels. As evidenced in the history of the ZEV program, technological development that is slower than expected can lead to higher cost and failure to achieve performance targets (Bedsworth and Taylor 2007). Uncertainty exists in the pace of technological development, associated costs, and the market penetration of new technologies. In addition, in the case of biofuels, there is uncertainty with regard to the broader environmental implications of biofuel development and use, including associated changes in land use and impacts on food production. In the case of VMT reductions, there is less uncertainty with regard to the environmental benefits—if programs are implemented and successful in achieving behavioral change. But there is significant uncertainty in understanding and modeling the impacts of land-use changes on VMT (Bartholomew and Ewing, 2009), and also with regard to behavioral responses to efforts to reduce VMT and whether there will be the political will to implement the programs.

Evaluating Policy Options

Evaluating the policy options to reduce transportation's environmental footprint requires looking at several criteria. In this analysis, we consider GHG emission reductions, reductions in smog-forming emissions (translated into public health impacts),[15] and technology and fuel costs. The analysis proceeds in three steps:

1. Estimate potential GHG emission reductions associated with a given policy option,
2. Estimate potential smog-forming emission reductions associated with a given policy option and translate this into effects on public health,
3. Estimate the technology and lifetime cost of each policy option.

While it will not always be possible to maximize the benefits for all criteria, it is important to understand how policy choices affect each of these issues.

We consider three technology options for the passenger vehicle fleet:

1. E85 (85% ethanol blended with gasoline) in flex-fuel vehicles,
2. Battery-electric vehicles,
3. Fuel cell vehicles.

In the case of E85, we consider corn-based ethanol (the main source of ethanol currently used in the state) as well as cellulosic ethanol. In addition, we examine the emission reductions from each technology option when accompanied by reductions in VMT, both from land-use change alone and from land-use change accompanied by transit investments and implementation of pricing policies. We also estimate the impacts of VMT reduction alone, without additional improvements in vehicle and fuel technology.

Generally, when comparing the GHG emissions from different options for the transportation sector, it is useful to consider the full life cycle emissions of the fuel and the vehicle, called a well-to-wheels analysis. A well-to-wheels analysis accounts for the production, transport, and use of a vehicle fuel. This is particularly important for biofuels that can be produced from many different crops and through different processes, as well as for fuels such as electricity that have no tailpipe emissions but that can contribute significant emissions in the development of the fuel. All of our analyses of GHG emissions in this paper use well-to-wheels emission factors.[16]

To estimate the GHG emission reductions that will result from policy changes, it is necessary to understand changes in the vehicle fleet, or stock, over time. Some policies will affect only new vehicles and, thus their resulting benefits will only be realized as older vehicles leave the fleet and newer vehicles enter the fleet. Companion incentive programs can provide a tool for accelerating the turnover of the vehicle fleet (e.g., "Cash for Clunkers" or a similar incentive program that provides rebates for the purchase of cleaner, new vehicles). Some changes in vehicle activity can be implemented across an entire fleet and do not depend on

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[15] Although GHG emission reductions are also undertaken with the ultimate goal of avoiding the negative impacts of global warming on the state's economy and society (including public health), these effects are less direct than in the case of smog-forming emissions. Moreover, they depend not only on California's actions but also on actions at the national and global level.

[16] Well-to-wheels emission factors can also be used for smog-forming emissions, but because the upstream emissions are regulated separately from the tailpipe emissions (through emission limits on power plants, refineries, etc.), they are not included in this analysis. Also, the pollution effects of these upstream emissions are relevant in the basins where they are produced, which will often be a different basin from the location of vehicle use. Most regulations for GHG emissions from the transportation sector, on the other hand, take a well-to-wheels approach, given the global nature of the pollutant.

turnover to penetrate the fleet. One benefit of policies that affect the entire vehicle fleet, such as VMT reduction, is that each avoided mile of travel by an older vehicle will provide larger environmental benefits than avoided travel by a newer, cleaner vehicle.

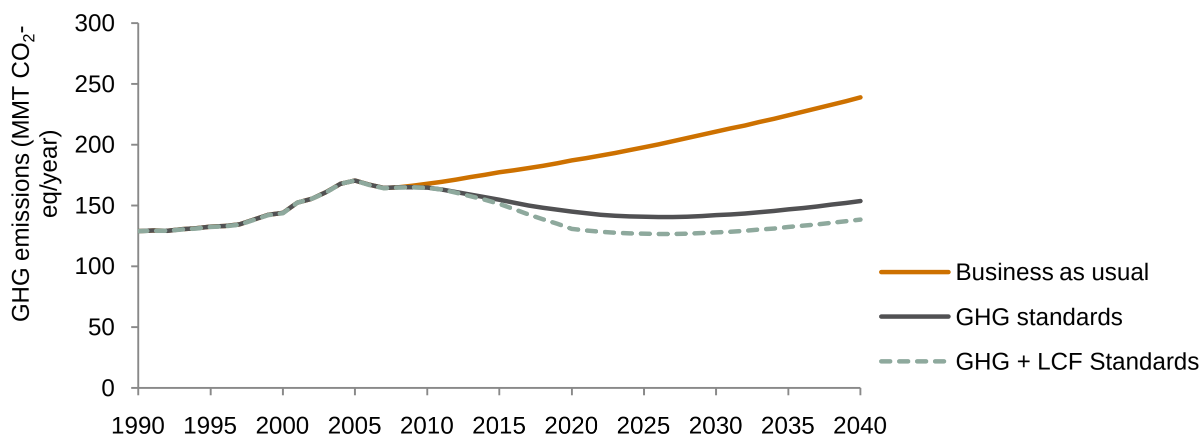
For this analysis, the vehicle stock (the number of vehicles by model year and class for each calendar year) was taken from CARB's vehicle stock model, or EMFAC (EMission FACtors) model (California Air Resources Board, 2006a). For the purposes of this analysis, we extracted information on the number of vehicles, VMT, and criteria pollutant emissions by each model year of vehicle for each calendar year. When looking at technology penetration, we assumed that a certain portion of the VMT for each model year and calendar year was traveled by a certain vehicle type. Data on fuel properties were taken from the LCFS regulatory materials (California Air Resources Board, 2009a, 2009b). Cost data were collected from analyses prepared for CARB, the California Energy Commission, and the U.S. Department of Energy's Annual Energy Outlook. For additional details on the calculations, see the technical appendix.

GHG Emission Reductions

We used the vehicle stock model described above to estimate GHG emission reductions, calculating the amount of energy required to travel a given distance. Then, using well-to-wheels estimates of emissions per unit of energy for different fuel choices, we calculated GHG emissions. Estimates of GHG emissions per unit of energy from the Low Carbon Fuel Standard documentation were used for the calculations (California Air Resources Board 2009a, 2009b).

Figure 8 shows how the state's currently adopted policy efforts will affect light-duty GHG emissions over time. The top line represents baseline emissions absent any new policies affecting vehicles, fuels, or VMT. The "GHG standards" and "GHG + LCF standards" lines show emissions with the implementation of the state's GHG standards for new vehicles, alone, and with the reduction of fuel carbon intensity through the low carbon fuel (LCF) standard, respectively. These lines represent policy implementation, but do not make any assumptions about which technologies or fuels are adopted to meet these policy goals.

FIGURE 8
GHG emissions under currently adopted policies



SOURCE: Author's calculations.

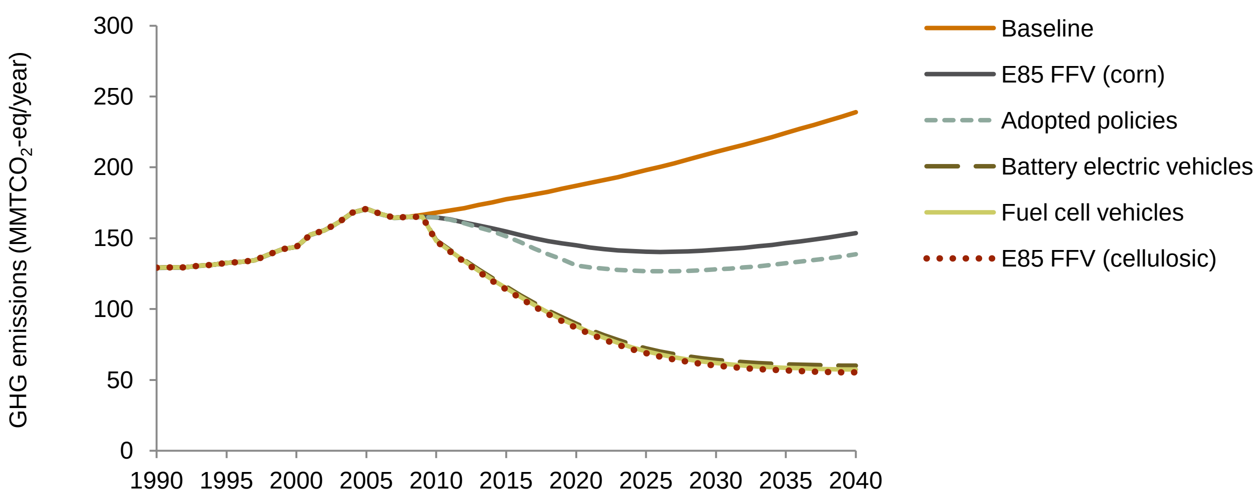
NOTE: The GHG and LCF standards are not likely to be fully additive because alternative fuels can serve as an alternative compliance pathway under the GHG standards. Thus, this figure likely overestimates the impact of the combined policies.

Figure 8 illustrates a very important fact: Policies adopted to date provide only a starting point for reducing GHG emissions. As the figure shows, absent additional reductions, GHG emissions will begin to increase again by 2030 as a result of continued population and VMT growth. Therefore, additional reductions will be needed to make progress toward the 2050 emission reduction target of 80 percent below 1990 levels.

Figure 9 shows GHG emission reductions with the introduction of additional vehicle technologies and fuels into the fleet (assuming vehicle efficiencies equivalent to those under the state's GHG emission standards). In all cases, the assumption is made that beginning in model year 2010, *all* new cars are of a particular technology type. The magnitude of the technology introduction is not meant to be realistic, but the results are meant to illustrate the relative magnitudes of the emission reductions possible with different technologies. More realistically, these technologies and vehicle types would be introduced more slowly into the vehicle fleet. (In addition, some technologies will not yet be ready for the market.) The lines showing baseline emissions (i.e., business as usual emissions) and the reductions achieved by adopted policies are retained in the figure to provide some perspective on the magnitude of the reductions achieved with each technology option.

These implementation scenarios all provide emission reductions above and beyond adopted policies, with the notable exception of E85 vehicles using ethanol derived from corn. Including the indirect emissions associated with the production of the average ethanol used in California, its carbon intensity is approximately equivalent to that of standard California reformulated gasoline. Therefore, using E85 produced from corn-based ethanol provides almost no GHG emission reduction benefit and will not be adequate to achieve the goals under the low carbon fuel standard. The other technology scenarios illustrate the magnitude of reductions needed to work toward the 2050 target. Battery-electric, fuel cell, and flex fuel vehicles using cellulosic ethanol all have potential to make significant, sustained GHG emission reductions. Interestingly, all three technologies achieve roughly the same level of reductions.

FIGURE 9
Emission reductions from different technology options

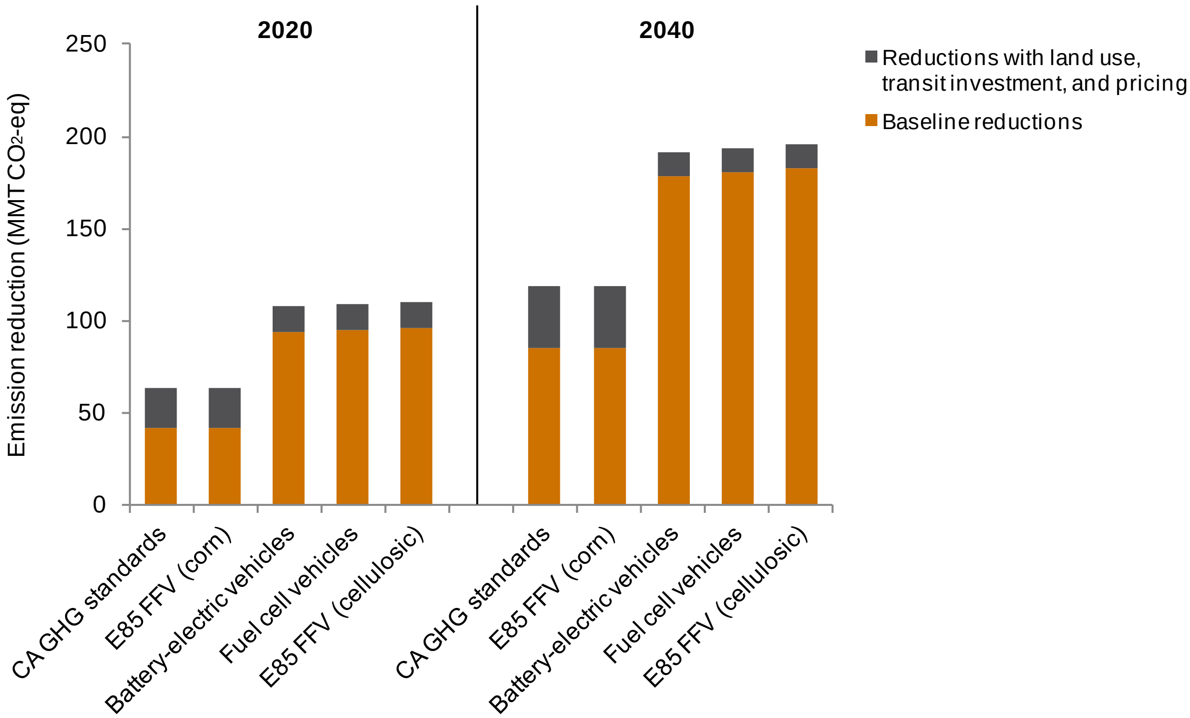


SOURCE: Author's calculations.

NOTE: "Adopted policies" includes the GHG emission standards for new passenger vehicles and the low carbon fuel standard. All technology scenarios assume that beginning in model year 2010, all new cars are sold with a given technology.

Efforts to reduce VMT will provide additional GHG emission reductions when paired with each of these policies. The additional reductions attributed to the aggressive land use, transit investment, and pricing scenario are shown in Figure 10. As Figure 10 shows, VMT reduction provides larger benefits for higher emitting vehicles. In the case of zero-emission vehicle scenarios, reducing VMT has no impact on tailpipe emissions since the emissions are already zero; therefore, the only impact observed is from the reduction in VMT from the older vehicles in the fleet. As a larger share of the fleet is made up of zero-emitting vehicles, the impact of VMT reduction lessens, as seen in the smaller benefit in 2040.

FIGURE 10
Emission reductions with land use, transit investment, and pricing policies in 2020 and 2040



SOURCE: Author's calculations.

Air Quality and Public Health Benefits

To compare the air quality-related public health impacts of the different policy options, we began by estimating the amount of reactive organic gases, oxides of nitrogen, and particulate matter emission reductions associated with each option. The EMFAC model provided baseline outputs of these pollutants, assuming the current vehicle fleet mix. Reactive organic gases, oxides of nitrogen, and particulate matter all contribute to air pollution that contributes to illness and death. Each of the technologies considered can have an impact on emissions of these pollutants as well as GHGs. For this analysis, we assumed an emission factor for each of these pollutants relative to the baseline for each technology. We assumed that for battery-electric and fuel cell vehicles, the tailpipe emissions would be zero. For the reduction in VMT, we eliminated the emissions associated with reduced miles.

There is uncertainty in what effect, if any, flex-fuel vehicles using E85 (from either corn or cellulose) will have on emissions. Given the need to meet existing tailpipe emission standards, they are required to be as clean as existing gasoline vehicles. Overall, studies on criteria pollutant emissions from E85 FFVs show mixed results (California Air Resources Board, 2009b, see Appendix F6). Although, one study estimates that E85 will result in a statistically significant reduction in tailpipe NOx emissions (Graham, Belisle, and Bass, 2008), another has shown an increase in emissions from E85 vehicles and a resulting increase in ozone concentrations (Jacobson, 2007). Therefore, we evaluate flex-fuel vehicles under the assumption they are identical to gasoline vehicles, but also assuming there is a 35 percent reduction in tailpipe NOx emissions.[17]

We then translated the reductions in these emissions to deaths avoided and several morbidity endpoints using the methodology from CARB's Goods Movement Emission Reduction Plan (California Air Resources Board, 2006b). Our application of the methodology was similar to that employed by Bailey et al. (2008). We estimated the reductions in emissions of each of these pollutants in 2020 for each of the technology scenarios shown in Figure 9, as well as for reductions in VMT.

Table 4 shows the deaths avoided and reductions in morbidity endpoints for four different transportation technology pathways, each measured against business as usual emissions. These estimates show the relative health benefits of these technologies. As above, the results provide an estimate of the relative health impacts of each of these technology pathways, but are not realistic depictions of what the vehicle fleet will look like in 2020. The largest health benefits are provided by the zero-emission vehicle technologies—battery-electric and fuel cell vehicles. Absent the NOx reduction, E85 provides no additional health benefits. For the calculations in this table, the VMT reduction scenarios are evaluated on their own, not in combination with the technology options. (As shown in Figure 10 above, the incremental benefits from VMT reduction policies would be lower if these policies were combined with the advanced technology vehicles that emit less).

In contrast to the analysis of GHG emission benefits above, the table does not report health benefits from the implementation of currently-adopted policies designed to reduce GHG emissions. There is a wide range of potential impacts of these policies on smog-forming emissions (and, consequently, on public health), depending on which technologies are chosen to meet the standards. For instance, if battery-electric or fuel cell vehicles are used to meet the low carbon fuel standard, there will be larger health benefits than if it is met through the use of ethanol. The GHG emission standards are likely to be achieved primarily through improvements in vehicle efficiency, which will not reduce smog-forming emissions.

[17] This reduction in NOx is in line with estimates provided by Graham, Belisle, and Bass (2008). In addition to uncertainty regarding the impact of the fuel, there is also uncertainty regarding which fuel is used in a flex-fuel vehicle. Since both regular gasoline and E85 can be used, it is unlikely that the full benefit of E85 will be realized over the lifetime of the vehicle because fuel use will depend on availability, price, and other factors.

TABLE 4
Annual health benefits of different technology and policy pathways

	Cases/Year						
	Premature mortality	**Hospitalization (respiratory)**	**Hospitalization (cardiovascular)**	**Asthma and other lower respiratory symptoms**	**Acute bronchitis**	**Work loss days**	**Minor restricted activity days**
2006 Baseline rate, light-duty vehicles	957	195	358	24,813	1,997	147,113	834,042
BEV and Fuel cells	366	74	136	9,553	753	55,456	308,946
VMT-land use only	5	1	2	120	10	703	3,944
VMT-land use +	120	24	45	3,129	249	18,299	102,604
E85 with NOx benefit	6	1	2	156	13	963	5,581

NOTES: The baseline rate for light-duty vehicles was calculated using the 2006 statewide emission inventory for ROG, NOx, and PM-10 and the health endpoint factors from the Goods Movement Emission Reduction Plan (California Air Resources Board 2006b, page A-71). "VMT-land use +" refers to VMT reduction achieved through land use, transit investment and aggressive pricing. These reductions are measured relative to business as usual emissions.

Cost

Many of the technologies examined here will involve increased up-front costs due to more expensive vehicles, but these costs will be at least partially offset by savings from reduced fuel costs over the lifetime of the vehicle. Of course, the cost of the fuels used by each technology will vary. Table 5 shows the technology and fuel costs for options considered in this paper. Cost estimates for vehicle technology changes were collected from a number of analyses prepared for state regulatory efforts, including the development of the state's alternative fuel investment strategy under AB 118, the alternative fuel strategy developed under AB 1007, the technology assessment for the ZEV program, and the regulatory documents for the state's GHG emission standards for new passenger vehicles.

As Table 5 shows, fuel cell and battery-electric vehicles have a substantial price premium relative to today's conventional vehicles. The range in technology costs stems from uncertainty in technological development and market penetration. In addition, in the case of the 2020 baseline vehicle (i.e., one that meets the 2016 GHG emission standard), the range depends on what technologies are employed to improve vehicle efficiency. Fuel cost estimates for E85, gasoline, and electricity were collected from the Department of Energy's Annual Energy Outlook and reflect fuel prices in 2020 for a low oil price scenario and a high oil price scenario. The range in electricity prices includes the range provided in the Annual Energy Outlook, but the high and low were taken from the data collected for the Low Carbon Fuel Standard. Hydrogen prices are derived from the proceedings for the development of the state's alternative fuel investment strategy (AB 118).

TABLE 5
Fuel and technology costs of different vehicle technologies

Policy option	Fuel cost ($2007/gallon gasoline equivalent)		Technology cost, relative to today's vehicle ($2007)		Lifetime fuel cost savings relative to today's vehicle ($2007)	
	Low	High	Low	High	Low	High
2020 Baseline vehicle	$ 1.83[b]	$ 4.57[b]	$284	$ 1,958	$ 4,391	$ 10,940
E85 FFV (corn)	$ 2.97 [b]	$ 6.95[b]	$0	$ 150	$ 678	$ 3,168
E85 FFV (cellulosic)	$ 2.40[a]	$ 3.19[a]	$0	$150	$ 2,540	$ 15,434
Battery-electric vehicle	$ 1.00[a]	$ 1.33[a]	$ 8,000	$ 15,000	$ 7,109	$ 21,499
Hydrogen fuel cell vehicle	$ 1.26[a]	$ 4.25[c]	$6,500	$ 30,000	$ 6,262	$ 11,969

SOURCES: [a]California Air Resources Board, 2009a.

[b]Energy Information Administration, 2009.

[c]Harris, 2009.

NOTES: The 2020 baseline vehicle refers to a conventional gasoline vehicle that has the technology to meet the 2016 GHG standard for new passenger vehicles. Fuel prices for battery-electric and fuel cell vehicles are given in dollars per gallon gasoline equivalent. All fuel cost savings are calculated relative to today's average vehicle. The calculation was completed for a light-duty automobile and assumes a 5 percent real discount rate for future fuel purchases and VMT (from EMFAC) for a 13-year, approximately 170,000 mile vehicle lifetime.

One measure of the cost-effectiveness of a vehicle technology improvement is whether or not the lifetime fuel savings (the final set of columns in Table 5) is greater than the initial technology investment (the second set of columns in Table 5). Both fuel cell and battery-electric vehicles entail significant vehicle costs as compared to a vehicle that meets the state's GHG standards in 2020 and an E85 FFV. Achieving lower up-front costs for these technologies will depend on significant improvements in technology and increased market penetration. For both battery-electric and fuel cell vehicles, the substantial initial investment is offset by the lifetime fuel savings only in the case of high gasoline costs and low technology costs.

The heavy-duty sector: Effects of emission reduction on mortality and morbidity

As light-duty vehicles have become cleaner, the contribution of heavy-duty and off-road vehicles (e.g., trucks, buses, and construction vehicles) to the emissions inventory of smog-forming pollutants has become more important. Thus, the heavy-duty sector is a worthwhile consideration for policies seeking to achieve significant public health benefits as well as GHG emission reductions. Among all of the state's recommended climate change measures, addressing heavy-duty diesel vehicle GHG emissions ranks second for achieving health co-benefits (Bailey et al., 2008).

A number of regulations have been passed to reduce NOx and PM emissions from diesel vehicles. In addition, a number of early action measures adopted under AB 32 target diesel sources. Two of these regulations are shown in the table below. The truck and bus regulation was passed by CARB in 2008. It requires that all trucks and buses in California meet 2010 model year emissions performance levels by 2023. Port electrification was approved by CARB as an early action measure under AB 32 in 2007. Port electrification would allow for docked ships to run off electrical power instead of using an auxiliary combustion engine.

Reductions in annual occurrences

Health endpoints	Truck and bus regulation	Port electrification option
Premature mortality	164	61
Hospitilization (respiratory)	33	12
Hospitilization (cardiovascular)	61	23
Asthma and other lower respiratory symptoms	4251	1,578
Acute bronchitis	338	127
Work loss days	25,034	9,423
Minor restricted activity days	140,749	53,464
GHG emission reductions in 2020 (MMTCO$_2$-eq)	0.01	0.5

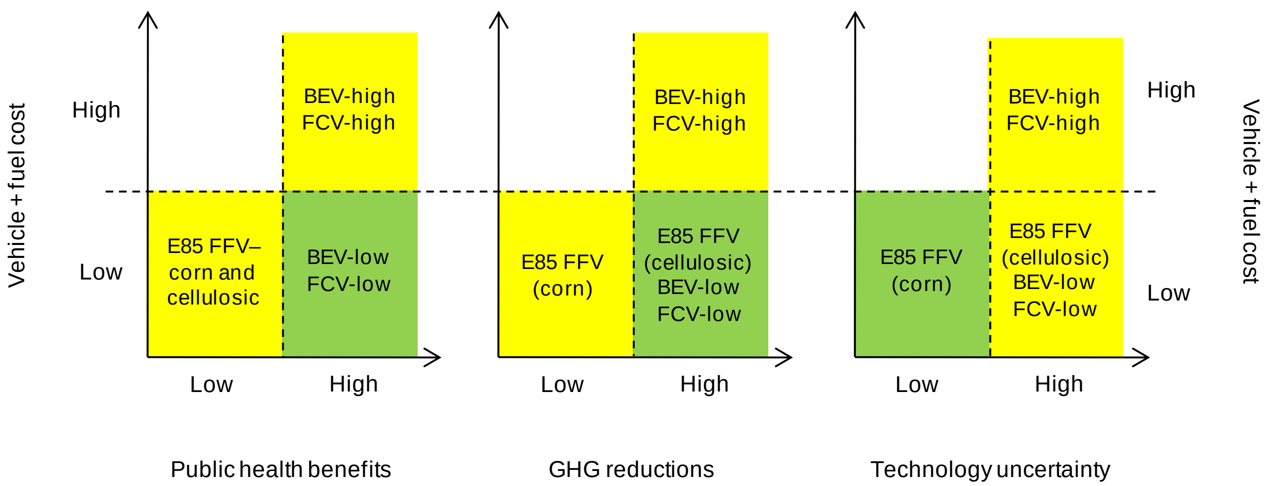
NOTES: Emission reduction estimates from (California Air Resources Board 2007, 2008a).
Health benefits estimates based on author's calculation (see technical appendix for details).

Both the truck and bus regulation and the port electrification option provide fewer GHG emission reduction benefits (last row in above table) than the various light-duty vehicle policy options discussed in the text, but both provide relatively large health benefits. In both cases, the health benefits are between those achieved through zero-emission vehicles and aggressive VMT reduction policies (Table 4).

Results and Discussion

California needs to transform its transportation sector to meet its air quality and climate change goals. This transformation should include new vehicle technologies and fuels, as well as reductions in VMT. However, as shown in Figure 11, none of the technology options considered in this paper rate favorably across all metrics—benefits to public health, contributions to climate change efforts, cost, and technological uncertainty. As the figure shows, it is desirable to achieve large public health benefits and GHG emission reductions, with low levels of technological uncertainty and at low cost. These are the green (i.e., more darkly shaded) squares in Figure 11. Yet, there is not a single option that lands in all three of the green squares. Thus it behooves policymakers, industry and environmental leaders, and the general public to understand the tradeoffs among the various options.

FIGURE 11
Tradeoffs among technology options



NOTE: The total costs for BEV and FCV are shown for the lower end of the technology cost (low) and the high end of the technology cost (high). The cutoff for high and low total cost is whether or not the fuel cost savings for the technology offset the additional up-front cost. The other rankings are qualitative and relative to one another.

Understanding Tradeoffs

The options that appear to provide the greatest public health and climate benefits—battery-electric and fuel cell vehicles (BEV and FCV)—also entail high potential costs and high levels of uncertainty regarding the technological development and market penetration needed to bring down the cost. It will be necessary to reduce these costs to move these technologies along to the more favorable green (i.e., darker) squares. E85 flex-fuel vehicles that run on cellulosic ethanol appear to be able to provide large climate change benefits at a relatively low cost; but they do not provide corresponding health benefits, and there's a high level of uncertainty surrounding the technology. This uncertainty arises from both the technological development of the vehicles and the indirect impacts on GHG emissions and the food supply as a result of increases in acreage cultivated for biofuel crops.

Maintaining California's Focus on Public Health

California's environmental leadership in air quality and automotive regulations has long been driven by the goal of protecting public health. This goal will remain a guiding force in designing policies and making technological choices. Regions of the state that are not in compliance with air quality standards need to focus more attention on reducing emissions. Ideally, efforts to address climate change should provide air pollution and public health co-benefits. In cases where this is not possible, the trade-offs need to be clearly understood, and meaningful compensatory measures should be considered. For example, if a particular policy leads to an increase in emissions, offset programs should be developed to achieve emission reductions from another source.

Battery-electric and fuel cell vehicles appear to provide significant GHG emission reduction benefits, and to benefit public health as well. While flex-fuel vehicles that use E85 derived from cellulosic materials appear to provide significant GHG emission reductions, their public health benefits appear low. Indeed, some studies point to potential increases in smog-forming emissions. This uncertainty underscores the need for additional research examining the problems and benefits associated with biofuels.

Managing Uncertainty

Each of the vehicle technology and fuel options examined here, with the exception of corn-based ethanol, is likely to be included among efforts seeking to reduce GHG emissions from the transportation sector. California's low carbon fuel standard and zero-emission vehicle program are full of promise but also face significant uncertainties.

The development and increased use of cellulosic ethanol must be undertaken with careful consideration of the potential impacts of dedicating more land to crop production. The magnitude of indirect emissions from cellulosic E85 appear to be significant. Given that this is an emerging issue, it should be explored further to understand the effects and to determine whether guidelines are needed to ensure that fuel production is carried out in a way that minimizes its impact. Similarly, the effect of biofuel production on the global food system needs to be better understood.

The policy options that look the most promising from the standpoint of public health and GHG emission reductions involve the development and deployment of new technologies, which naturally involve uncertainties in cost and performance. Zero-emission vehicles in the form of BEVs have appeared on the horizon as prototypes and small-production models for the past twenty years, but have continued to miss cost and performance milestones (Bedsworth and Taylor, 2007). New developments in battery technology and the success of hybrid-electric vehicles appear promising, but the timeline remains somewhat uncertain (Kalhammer et al., 2007). Cellulosic ethanol faces similar challenges because most of the ethanol currently produced in the United States is derived from corn.

Future policies need to accept this uncertainty and to strongly promote technology development, focusing on the emissions performance of vehicles and fuels. Policies on land use, transit investment, and pricing should support this technology push and help the state achieve its critical goals across all of the metrics discussed in this paper—climate change, air quality, and public health.

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Acknowledgments

I would like to thank Mike O'Hare, John Boesel, Michael Teitz, Ellen Hanak, and Jed Kolko for helpful comments on earlier versions of this paper. I would also like to thank Lynette Ubois and Gary Bjork for their excellent editorial guidance. In addition, Elizabeth Stryjewski provided excellent research assistance in the latter stages of this project.

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