Achieving California's Greenhouse Gas Goals: A Focus on Transportation

A Report for Next 10

By the Policy Institute for Energy, Environment and the Economy of
the University of California, Davis

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Report Overview

The California legislature, in passing Assembly Bill 32 ("AB 32") or the California Global Warming Solutions Act of 2006, required the state to reduce its greenhouse gas emissions to 1990 levels by the year 2020. As part of AB 32, the Air Resources Board was required to develop a Scoping Plan describing the measures to meet the goals, in consultation with other state agencies. This report focuses on the core suite of policies adopted by the State of California to reduce greenhouse gas emissions from transportation as part of the AB 32 Scoping Plan. This suite includes:

- The Pavley regulations, as integrated in the National Program (Chapter 2);
- The Zero Emission Vehicle regulation (Chapter 3);
- The Sustainable Communities and Climate Change Act, or SB 375 (Chapter 4);
- The Low Carbon Fuel Standard (Chapter 5); and
- The Fuels in the Cap component of the Cap and Trade program (Chapter 6).

While discussed in separate chapters, these policies should be thought of as an interconnected suite. The carbon benefit of each will depend not only on its own design and implementation, but also on the design and implementation of the others.

Nearly ten years after AB 32 was passed, the state is considering the steps beyond 2020 for California. In his fourth inaugural address, Governor Jerry Brown called upon the state to reduce its petroleum use by up to 50 percent by 2030. The subsequent Executive Order B-30-15 establishes a statewide greenhouse gas reduction target of 40 percent below 1990 levels by 2030.

Our intention is to assess the current transportation policies and programs included in AB 32 on a variety of dimensions, such as cost effectiveness, potential for carbon emissions abatement, technological feasibility, and others. For these assessments we predominantly rely on a critical examination of published research, analysis and policy documents. Each chapter draws on the expertise of UC Davis researchers with deep understanding of the particular topic.

Each chapter begins with a list of summary findings specific to a particular policy. **We list below a few selected general findings from our assessment:**

- A future transportation system that achieves deep reductions in greenhouse gas emissions consistent with the state's 2050 climate goals is technically achievable.
- While this future system could provide mobility at a cost lower than the current system and with significant social benefits, there are real transition costs and other non-market barriers that must be overcome.

- California has adopted a suite of ambitious policies to reduce carbon emissions from the transportation sector and, in doing so, the state is providing experience and lessons for other jurisdictions that are interested in pursuing similar policies.
- California has the resources to undertake the challenging process of policy innovation, development, implementation, testing and refinement that might be difficult for other states with more limited resources.
- Although most of these policies are in their early stage of implementation and they are generally on track to meet their respective and combined goals, continuous progress evaluation is important.
- The suite of policies is directed predominantly to the supply side of the transportation system. As such, it is heavily dependent on technology innovation and consumer acceptance of innovations on vehicle technologies, fuel characteristics, and different land use patterns. The cap and trade program will generate a price signal that may help induce users' behavioral adjustments. The strength of such price signal is relatively uncertain, due to the complex interactions between cap and trade and other policies.
- There is a strong need for data collection, analysis and continued research and development to improve on technologies and policies designed to achieve climate goals. Building this informational foundation will help reduce uncertainty, improve the efficacy of public policy and business strategy, and reduce wasted resources.
- California is leading the nation in market adoption of plug-in electric vehicles, both in absolute numbers with more than 100,000 vehicles on state roads, as well as percentage of new vehicle sales. Building upon the ZEV regulation, the state has increasingly recognized and worked toward partnerships with industry and other stakeholders to foster ZEV markets. The clear direction provided by Governor Brown and the establishment of the Plug-in Electric Vehicle Collaborative, are instrumental to help key stakeholder organizations to work collaboratively toward the same goal.
- While uncertainty is a natural part of policy, there exist opportunities to reduce the uncertainty associated with the emissions reductions from certain policies. Sources of uncertainty include the extent to which these policies can affect the overall level of demand for travel, vehicles and fuels, the difference between the estimated emissions from life-cycle analysis and testing compared to the real-world emissions, and the level of resource-shuffling or movement of activity to jurisdictions that are not covered by the policy. Furthermore some policies, such as SB 375, rely heavily upon incentives and voluntary implementation at the level of the local jurisdiction. Some of this uncertainly can be addressed through further analysis and policy refinement, but other sources are best addressed by expanding the coverage of the policies beyond California.
- The expansion of cap and trade program to include transportation fuels, meant to ensure the largest source of state emissions is captured under the cap, induces a price signal on the carbon content of fuel. Carbon pricing will not only moderate carbon consumption, it can also help finance the implementation of

climate policies and programs. This funding mechanism could be critical particularly for local and regional governments that struggle to find sources of revenue.

- More research is needed to help policymakers understand opportunities to refine these policies to increase certainty and efficiency. As an example, research would help understand the ways in which the transportation fuels element of the cap and trade program will interact with other transportation climate policies.
- Broadly, the cap and trade program can be viewed as a backstop for the containment of carbon emissions under specified limits, even in the case that other policies failed to meet some of their goals.

California's Climate Policy Legacy

Gustavo Collantes and Anthony Eggert

California became the first state in the nation to regulate carbon emissions from transportation when, in September 2004, the California Air Resource Board (CARB) adopted standards to reduce greenhouse gas (GHG) emissions from passenger vehicles, pursuant to Assembly Bill 1493 (Pavley, 2002). Since then, the state has taken bold action to tackle climate change.

With Executive Order S-3-05, Gov. Arnold Schwarzenegger set a series of targets to reduce statewide emissions of greenhouse gases, with the final goal of cutting emissions to 80 percent below 1990 levels by 2050. With the passage of the California Global Warming Solutions Act of 2006 (Assembly Bill 32, Nunez-Pavley), signed into law by Governor Schwarzenegger in 2006, the Legislature declared that climate change "poses a serious threat to the economic well-being, public health, natural resources, and the environment of California" and while recognizing that action is needed at the national and international levels, "action taken by California to reduce emissions of greenhouse gases will have far-reaching effects by encouraging other states, the federal government, and other countries to act." AB 32 requires California to cut GHG emissions to 1990 levels by 2020[1], and directs CARB to adopt cost-effective and technologically feasible rules and regulations that maximize statewide emissions reductions that at least meet that goal.

In 2009 CARB developed a scoping plan for achieving the emissions reductions required by 2020 and began implementation of a set of early action measures in 2010, which included policies to start expeditiously moving the state toward meeting its carbon emissions goal. CARB included in the scoping plan a suite of policies and programs, which included among others the extension of the Pavley vehicle GHG regulations and existing Zero Emission Vehicle program into the Advanced Clean Cars program, and creation of a Low Carbon Fuel Standard and a greenhouse gas emission cap and trade program. All of these programs are discussed in this report.

In 2011, Governor Brown issued Executive Order B-16-2012 to complement the state's existing 2050 GHG reduction goals by specifying the same emissions reduction in the transportation sector. The order sets in motion a plan for the support of zero emission vehicles, including plug-in electric and hydrogen fuel cell vehicles, in recognition that such deep reductions in transportation emissions are technically possible and can be cost-effective but are unlikely to occur without bold public policy, strong public-private partnerships, early action, and sustained commitment.

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[1] Emission levels in 1990 were identified as 427 million metric tons of carbon dioxide equivalent.

[2] Intensity emission standards are limits on emissions per unit of output. In this particular case, the

California has focused much of its climate policy on transportation emissions because transportation is the single largest contributor to California's greenhouse gas emissions (Figure 0-1) and when the direct combustion emissions are combined with upstream refining and oil exploration, the sector accounts for nearly half of the state's carbon footprint.

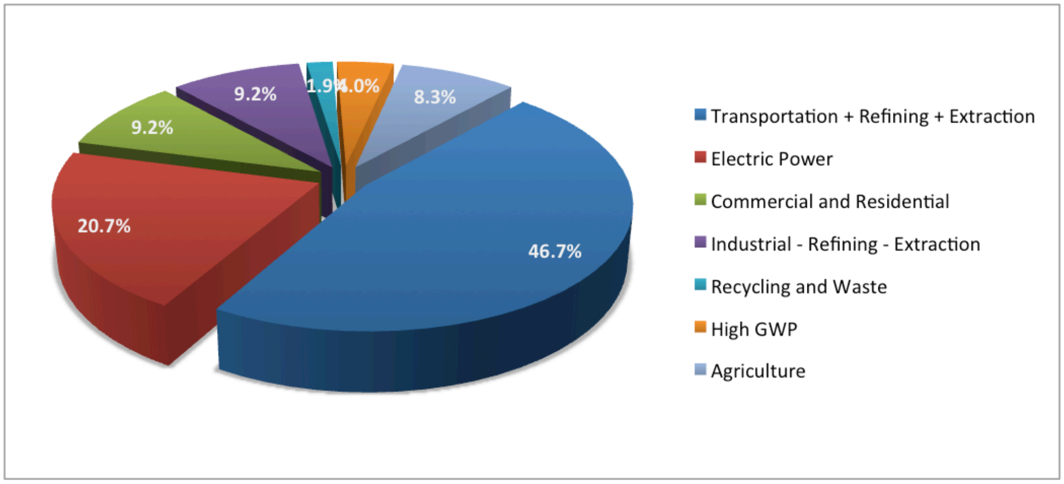

Figure 0-1. Greenhouse gas emissions in California, by sector (Source: CARB, 2014)

Earlier studies have used the so-called Kaya identity to summarize the factors that affect total carbon emissions from transportation as:

Emissions = Population x VMT x Vehicle efficiency x Fuel carbon

The beauty of the simple Kaya identity is that it can be presented as the direct product of the four selected factors. However, there are many more factors, including basic R&D, urban form and human behavior influencing the technologies and strategies that affect transportation emissions. Table 0-1 expands upon the Kaya framework and includes five additional and interrelated critical factors: *innovation, infrastructure, mobility, mode, and vehicle operations*. Table 0-1 attempts to summarize these factors and how they are manifested on the supply and demand side. Though not yet strictly comprehensive, this expanded list of factors is more reflective of the actual set of mechanisms responsible for emissions.

Table 0-1 Factors that influence carbon emissions from transportation and how they are manifested on the supply and demand side

Carbon Factor	Supply Side	Demand Side
Innovation	R&D Demonstrations Pilots Deployment	Early adoption
Construction	Construction practices Project size	
Mobility	Urban form Accessibility	Residential location choice Destination choice Trip planning
Mode	Road infrastructure Transit service Accessibility	Mode choice
Vehicle technology	Vehicle efficiency Vehicle powertrain	Vehicle type choice
Vehicle operations	System capacity System efficiency	Driving behavior Vehicle fueling behavior
Fuel	Fuel carbon intensity Fueling infrastructure	Fuel type choice Fuel consumption

Table 0-1 is useful in that it displays the key areas where policy can potentially be directed to reduce transportation carbon emissions, including activities on the supply and demand sides. California has established policies that target many of these activities, and, while the focus has initially been on the supply side, the state is increasingly pursuing complementary measures on the demand side.

Innovation: In this area, the state has established several programs that support the research, development and market testing of new technologies. For example, the Electric Program Investment Charge (EPIC) R&D program and the Alternative and Renewable Fuel and Vehicle Technology Fund (AB118/AB8), both administered by the California Energy Commission (CEC), support the development and deployment of innovative clean vehicle and fuel technologies. The state has also offered a number of incentives to encourage early consumer adoption of new transportation technologies. These incentives can be monetary (e.g. the Clean Rebate Vehicle Program offers rebates on the purchase of vehicles with zero emission capability) and non-monetary (e.g. granting zero emission vehicles access to high-occupancy vehicle highway lanes).

Construction: The construction of roads and buildings has carbon implications. These include the type and quantity of construction materials, the frequency and duration of repair that can cause traffic delays, and the surface conditions that can affect vehicle fuel economy and durability. Excavation during building construction releases carbon trapped in soils, and to the extent that developments encroach in agricultural land, emissions from indirect changes in land use may result.

Mobility: The purpose of the transportation system is to support the mobility needs of people and goods. Typically, mobility is measured in terms of vehicle miles traveled (VMT) and, all else equal, the higher the VMT the higher the levels of carbon emissions. Thus for policy the challenge is to reduce VMT without compromising other social and economic goals. The main policy tool adopted by the state to address this challenge is the ***Sustainable Communities and Climate Protection Act (SB 375)***, which promotes land use and transportation systems conducive to lower automobile travel. Chapter 4 in this report is dedicated to SB 375 and related policies. Travel choices can also be influenced putting a price on carbon emissions; this is done with the state's cap and trade program.

Mode: Policies that encourage the use of alternative modes are an essential part of strategies to reduce emissions from the transportation sector. ***SB 375*** is also concerned with promoting strategies conducive to more walking, bicycling, and use of public transportation. Indeed, mode choice is inextricably linked to urban form and land use patterns. Low density and sprawling development, characteristic of urban growth in California for decades, is not conducive to financially sustainable public transportation. Similarly, auto-oriented neighborhood and regional development discourages, or often makes it impossible altogether, to switch to walking or bicycling, because of the large distances involved, personal safety concerns, and other factors.

Vehicle technology: California has long been the national leader in promoting vehicle technology improvements to reduce tailpipe emissions. Thanks in large part to bold regulatory processes started in California in the late 1970s, the personal automobile has dramatically reduced its contribution to the local air pollution problem in the United States. More recently, and as noted above, with the passage of Assembly Bill 1493 in 2002, California pioneered the regulation of vehicle emissions of greenhouse gases with CARB's adoption of the ***Pavley Standards*** in 2004. In 2009, California extended its vehicle GHG standards and, working with the auto industry and the Obama administration, recognized the ***National Program***, administered by the U.S. EPA, as equivalent with state vehicle emissions requirements. These regulations are discussed in Chapter 2.

Carbon mitigation goals cannot be met only with fossil-fueled vehicles—the mass commercialization of vehicle technologies that can use energy carriers that can be produced from low-carbon sources is critical. Electric drive vehicles, such as plug-in electric and hydrogen fuel cell vehicles are viable alternatives. To support the commercialization of electric drive vehicles, the state has included in the scoping plan the ***Zero Emission Vehicle (ZEV) regulation***, which requires auto manufacturers to sell increasing volumes of vehicles that can provide mobility without vehicle emissions. The ZEV regulation was once the only policy tool in the state to foster ZEV commercialization. Now, a number of additional measures add to the state's commitment to support innovation in this space. For example, Governor Brown's Executive Order B-16-2012 directed the state to work toward the rapid commercialization of zero emission vehicles. Chapter 3 in this report is dedicated the ZEV regulation.

Vehicle operations: Researchers at UC Davis and elsewhere find that the efficiency of road vehicles can vary widely depending on vehicle technology and the conditions in which they are operated. Regardless of EPA fuel economy ratings, a conventional vehicle stuck in traffic delivers in effect extremely low efficiency. Thus, the efficiency of the road system is critical to reap the benefits of increasing vehicle efficiencies. Transportation planners have a host of measures at their disposal to affect traffic flow, including road capacity, travel demand management, intelligent transportation systems, HOV/HOT lanes, variable tolling, etc. The challenge will remain, that demand for roads typically peaks at certain times, including rush hour and holidays. Similarly, the way users drive their vehicles has a tremendous impact on vehicle efficiency and consequently on carbon emissions. The use of heating and air conditioning, acceleration and driving speeds are some of the behaviors that strongly affect efficiency.

Fuel: The amount of fuel that a vehicle uses depends on several factors as described above. The quantity of emissions resulting from using a certain amount can vary widely depending on the type of fuel. The relative climate impacts of any two types of fuels can only be estimated by looking at lifecycle carbon emissions, commonly referred to carbon *intensity*—the emissions resulting from the entire process of fuel production and delivery. The state of California pioneered the regulation of fuel carbon intensity with the ***Low Carbon Fuel Standard*** (LCFS), which is discussed in Chapter 5 of this report.

California also implemented a ***Greenhouse Gas Regional Cap and Trade Program***, which is broad in scope, covering over 80% of all the emissions sources in the state and requiring reductions through 2020. The program works by inducing a cost on carbon emissions and creating incentives to reduce those emissions throughout the supply chain. The cap and trade program is unique in its inclusion of transportation fuels under the cap, which started in 2015, making it one of the first cap and trade programs in the world to do so. While the short-term response in transportation fuel use to these prices is likely to be small, in the medium to longer term the price signal will provide incentives for more efficient vehicles, lower-carbon fuels, and even better mobility choices (Morrow, Gallagher, Collantes and Lee, 2010; Knittel, 2013).

In summary, there is no individual ''Silver Bullet" technology or policy strategy that can achieve California's ambitious emissions goals. Instead, a portfolio of the most promising low-carbon technologies and policies that address vehicles, fuels, and vehicle miles traveled will be needed (Yang, 2009; CARB, 2009; Morrow, Gallagher, Collantes and Lee, 2010).

There will be real transition costs to move the state toward a lower-carbon transportation future. However, the costs of inaction would be much greater. Overall, studies suggest that the benefits of the transition could be quite large and much greater than the transition costs. Recent analyses suggest that the net present value of benefits associated with a transition to passenger vehicles that achieved an 80% reduction in greenhouse gas emissions by 2050 could be in the order of $300 Billion for California (Greene, 2013) and well over $1 Trillion nationally (NAS, 2013). The transition results in both private benefits such as reduced lifetime fuel costs and societal benefits including reduced damages from pollution and petroleum dependency. These projections are subject to considerable uncertainties, given the timeframes, the needed evolution of technologies and the complexity of the processes involved. It is also important to continue studying and evaluating the equity implications of these costs.

The Pavley Standards and the National Program

Gustavo Collantes

Highlights

- California adopted carbon emission standards from passenger vehicles in 2004 (Pavley) and later recognized the standards set by federal agencies (National Program) toward compliance with the state tailpipe GHG emission standards
- These programs set intensity standards or limits on emissions per vehicle-mile traveled for new vehicles, and are not concerned with limiting total emissions from these vehicles
- Recognizing the National Program is estimated to result in reductions of 109 million metric tons in emissions of CO_2 by 2020, compared to reductions of 132 million metric tons (MMT) that would result from adopting the more stringent Pavley standards
- California's recognition results in a stronger National Program with larger total emissions reductions at the national level, which are estimated at 307 MMT beyond what would have been achieved extending the 2011 Corporate Average Fuel Economy (CAFE) standards
- The cost to industry of meeting the 2012-2016 standards is estimated at up to $345 billion over the 2012-2050 timeframe, using a three percent discount rate
- Savings in fuel costs resulting from the regulation are estimated at $1.7 trillion over the 2012-2050 timeframe, using a three percent discount rate
- EPA estimates that, when fuel savings are accounted for, the costs of the regulation per ton of CO_2e are negative, at $-130 and $-220, by the years 2020 and 2030, respectively

Background

The State of California has been a leader in setting new-vehicle emissions standards. Three pillar programs are in place: the Low Emission Vehicle (LEV) program, the Zero Emission Vehicle (ZEV) regulation, and the Pavley regulation. In March 2012, with the California Air Resources Board (CARB) as the lead agency, the state adopted a new approach by combining these regulations into one single coordinated regulatory package—the Advanced Clean Cars (ACC) rules (CARB, 2012). The rules combine into a single package standards for criteria air pollutants and precursors (CAPs) and greenhouse gas (GHG) emissions, soot and requirements on the commercialization of zero emission vehicles. CARB incorporated the ACC rules into the AB 32 Scoping Plan, and as such it is an integral part of California's strategy to meet the state's GHG emission goals. In this chapter we focus on the Pavley regulation and the National Program (described below); we discuss the ZEV regulation separately in the next chapter.

California became the first state to regulate carbon emissions from transportation when, in September 2004, the California Air Resource Board (CARB) implemented Assembly Bill 1493 (Pavley), setting intensity standards[2] on the emission of greenhouse gases (GHG) from passenger vehicles. These standards, which became known as the Pavley regulations, apply to vehicle model years (MY) 2009 to 2016 and were incorporated into the Low Emission Vehicle II (LEV II) program in 2005. Pursuant of Section 209 of the U.S. Clean Air Act (CAA), the state needs to apply for a waiver from the U.S. Environmental Protection Agency (EPA) to amend or enact new regulations. Only on June 30, 2009, after a very unusual delay of five years, did the EPA grant California a waiver to adopt the Pavley standards.

In 2009, President Obama announced the decision to pursue a National Program setting fuel economy and greenhouse gas emission standards for light-duty vehicles, for the MY 2012-2016 period (The White House, 2009). Later, the President directed the agencies to further this effort and develop standards for MY 2017 through 2025 as well. CARB formalized its support of the National Program, and accepts compliance with the program toward compliance with mobile GHG standards set by the State of California.

The National Program standards for MY 2012-2016 are based on the footprint of the fleet produced by a manufacturer each year, with separate standards for passenger cars and light-duty trucks.

Scale of Potential Emissions Reductions

The Pavley regulation and the National Program are emission standards and set limits on average emissions, on a per-mile basis, for the fleet of new vehicles sold each year by each manufacturer. As such, these programs are not concerned with limiting total emissions from new vehicles. The expected total or absolute emissions for all vehicles can be estimated, though estimation will always be subject to uncertainties.

The Pavley standards are codified in §1961.1 CCR and their stringency levels over time are summarized in Figure 0-1.

[2] Intensity emission standards are limits on emissions per unit of output. In this particular case, the Pavley standards set limits on the amount of CO_2 emissions per vehicle-mile traveled.

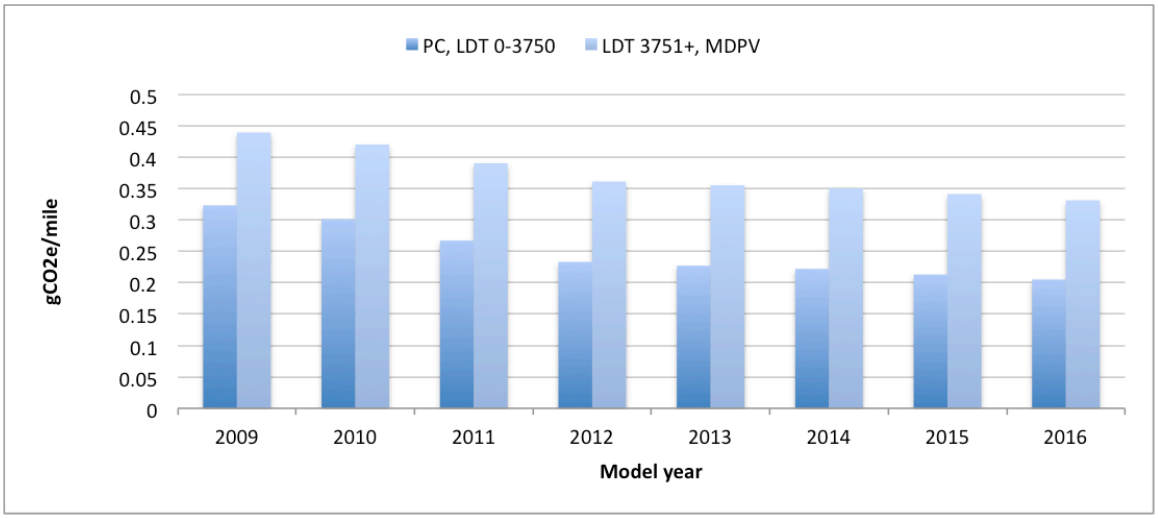

Figure 0-1. Progression of Pavley Standards, 2009-2016

According to CARB, because the Pavley standards are more stringent than those of the National Program from 2011 to 2015, the adoption of the National Program will result in slightly higher emissions of greenhouse gases in California and each of the states that had adopted the California program, relative to those that would result if the Pavley standards were binding. CARB, however, recognizes that supporting the adoption of a National Program will result in lower *total* emissions at the national level. As shown in Table 0-1, if the National Program was applied to all states, it would achieve 148 million metric tons of *additional* total reductions in greenhouse gases by the year 2020, relative to a scenario were the Pavley standards are applied to all states adopting the California standards and reductions in the rest of the states come from compliance with the Corporate Average Fuel Economy (CAFE) standards.

Table 0-1. Cumulative Reductions in Greenhouse Gas Emissions Under Different Programs

Policy implemented	Geographical scope	Emissions reductions (MMT) 2016	2020
Pavley Std in CA + 177 states, CAFE in other states	California	44	132
	California + 177 states	133	401
	Nationwide	241	793
National Program	California	33	109
	California + 177 states	99	325
	Nationwide	286	941

Data source: California Air Resources Board

Emission reductions are best estimated over the lifetime of the vehicle fleets starting with the first year of the program. Accounting for upstream emissions, EPA estimated that implementing the National Program would result in annual emissions reductions from light-duty vehicles of 307 million metric tons of CO_2-

equivalent by 2030; approximately equivalent to a 21 percent reduction relative to the baseline.[3] Given the long timeframes over which emissions are assessed, the effect of uncertainties on these estimates is large.

To estimate emissions reductions on the 2017-2025 phase of the program, the agencies prepared scenarios for two model years, namely 2020 and 2025. For each model, it starts with average fuel economy and emissions as prescribed by MY 2016 standards of 250 $gCO_2eq.$/mile. It then applies annual increased emission standard stringencies of 3, 4, 5, and 6 percent. This results in target fleet average emissions as described below.

Table 0-2. Emissions and fuel economy targets for various scenarios in the 2017-2025 stage of the National Program

Stringency increase (%/year)	Fleet average targets in 2020		Fleet average targets in 2025	
	Emissions ($gCO_2eq.$/mile)	Fuel economy (gallons/mile)	Emissions ($gCO_2eq.$/mile)	Fuel economy (gallons/mile)
3	221	40	190	46.8
4	212	42	173	51.4
5	204	44	158	56.2
6	195	46	143	62.1

EPA defined four technology pathways that could feasibly (as determined by EPA) attain the fleet average emissions targeted by each of the scenarios. The pathways are qualitatively described in Table 0-3, where darker colors represent more intense reliance on the particular technology:

Table 0-3. Definition of technology pathways considered.

Pathway	Technology			
	Advanced gasoline	Mass reduction	HEV	PEV
A				
B				
C				
D				

[3] The benefits of the programs were assessed relative to a baseline case. This baseline was defined assuming that MY 2011 CAFE standard continued indefinitely into the future. For the post-intervention emissions, it was assumed that MY 2016 standards continued indefinitely after 2016.

A note on on-road parameters

To measure tailpipe emissions, EPA tests vehicles using standardized dynamometer drive schedules (DDS). It has been long known that DDS do not accurately represent current typical on-road driving cycles (Inhaber, 1982). To partially account for this problem, EPA adopted adjustment factors for the purpose of this rulemaking. For internal combustion engines, EPA assumes a 20% difference between the values of fuel economy and GHG emissions obtained from the Federal Test Procedure (FTP) and Highway Fuel Economy Driving Schedule (HWFET) and those obtained in on-road driving (the latter being higher). For PEVs, EPA assumes a 30% gap in power consumption between the two-cycle test and the on-road (or actual) driving. This gap is higher than the 20% assumed for electric drive platforms for the MYs 2012-2016 final rule.

The increase in vehicle fuel economy is comparable to a reduction in the per-mile cost of driving. Thus, it may be expected that the implementation of the National Program (taken in isolation) can result in some increases in vehicle miles traveled (VMT)—a process known as the *rebound effect*. The rebound effect has been studied, for example, in Greening et al. (2000), Small and Van Dender (2007a, 2007b) and Sorrell and Dimitropoulos (2007). Small and Van Dender (2007a, 2007b) estimate the rebound effect over the 1997-2001 period to be 2.2% and 10.7% for the short- and long-term, respectively. These values are much smaller when compared with estimates for the 1966-2001 period (4.5% and 22.2% for the short- and long-term, respectively). The EPA analysis accounts for changes in VMT in response to changes in the fuel prices assuming price elasticities of travel demand of -10% and +10% for increases and decreases in the cost of driving, respectively.

A note on upstream emissions

To account for emission from electric drive vehicles, such as plug-in hybrid electric, full electric and hydrogen fuel cell vehicles, EPA proposes to assign these vehicles multipliers in the range of 1.2 to 2, so that each vehicle sold counts as more than one. Additionally, EPA proposes in the emission factors of zero for the electric part of the miles driven by these vehicles, thus excluding upstream emissions from electricity or hydrogen production. CARB believes that upstream emissions should be included in the treatment of these vehicles.

The Advanced Clean Cars rules include requirements on criteria pollutant emission levels. There is an increasing body of scientific literature pointing to the benefits of these emissions reductions to climate stabilization, although these are currently not directly estimated and accounted for by the agencies. Reductions in the emission of pollutants such as ozone, black carbon, particulate matter and others can have climate effects at the regional and global levels (e.g. Shindell et al., 2011).

Cost Effectiveness

To assess the costs involved in incorporating advanced technologies that would reduce new-vehicle emissions to levels consistent with the standards, the agencies drew information from a variety of sources, including existing studies, the process lead by California to implement the Pavley I standards, confidential information provided by the automakers and extensive third-party system “teardown” studies. The incremental cost of incorporating each of a large number of technologies (e.g. turbocharging, cylinder deactivation, continuous variable transmission, etc.) was estimated for five types of vehicles, namely small car, large car, minivan, small truck, and large truck. Similarly, the incremental cost of vehicle electrification was estimated, including incremental costs of hybrid, plug-in hybrid and full electric vehicles. Then, EPA estimated incremental costs for sets of technology packages applied to 19 different vehicle types. Finally, EPA commissioned third-party simulations of vehicles with technology packages incorporated into them. With this information, EPA estimated the average cost of meeting each of the four possible 2025 target emission standards described in Table 0-2, under each of the four possible technology pathways described in Table 0-3. Their results are shown in

Table 0-4. Projected average costs per-vehicle of meeting 2025 target emission standards

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Table 0-4. Projected average costs per-vehicle of meeting 2025 target emission standards

2025 emission target ($gCO_2eq./mile$)	Technology pathway cost ($/new vehicle)			
	A	B	C	D
190	$930	$850	$770	$1,050
173	$1,700	$1,500	$1,400	$1,900
158	$2,500	$2,300	$2,100	$2,600
143	$3,500	$3,200	$2,800	$3,400

Data source: EPA (2012)

EPA estimated that, on average, the cost per vehicle of meeting 2016 standards would be $869 and $1,098 for passenger cars and light-duty trucks, respectively (EPA, 2010). Table 0-5 shows the cost to industry for each of the years of the regulation period, as estimated by EPA. At the level of the manufacturer, estimated total annual per-vehicle costs for MY 2016 range from $455 for Toyota to $1,693 for Volkswagen.

Table 0-5. Cost to industry of complying with the National Program, in $ per vehicle unit produced.

	2012	2013	2014	2015	2016
PC	$342	$507	$631	$749	$869
LDT	$314	$496	$652	$820	$1,098
Combined	$331	$503	$639	$774	$948

Data source: EPA (2010)

Using projections of car and light-duty truck sales in each of the years in the regulation period, EPA estimates the total annual costs to each car manufacturer and to the industry as a whole of meeting the standards. The results for the industry are summarized in Table 0-6.

Table 0-6. Total annual costs to industry of complying with the National Program, in $Billion.

	2012	2013	2014	2015	2016
PC	$3.120	$4.967	$6.456	$7.960	$9.413
LDT	$1.821	$2.995	$3.878	$4.778	$6.225
Combined	$4.939	$7.966	$10.339	$12.735	$15.644

Data source: EPA (2010)

EPA then estimates the added cost to new-vehicle fleets that comply with the standards for each year between 2012 and 2050, relative to the cost of vehicles produced in MY 2011 to comply with the CAFE standards in that year. The net present value of these annual incremental costs are shown in Table 0-7 for discount rates of three and seven percent.

In EPA's assessment, the costs to industry will be offset by economic or monetized benefits resulting from the program. In particular, EPA estimates that fuel economy improvements will be such that savings to consumers will surpass the incremental cost of the new technologies, starting in 2016.

Using projections of fuel prices from the U.S. Department of Energy and estimating projections of VMT, the agencies develop projections of fuel expenditures as the emission standards are implemented. Figure 0-2 shows the annual savings in fuel expenditures projected for new vehicle fleets produced in each of the years between 2012 and 2016, over a period of ten years.

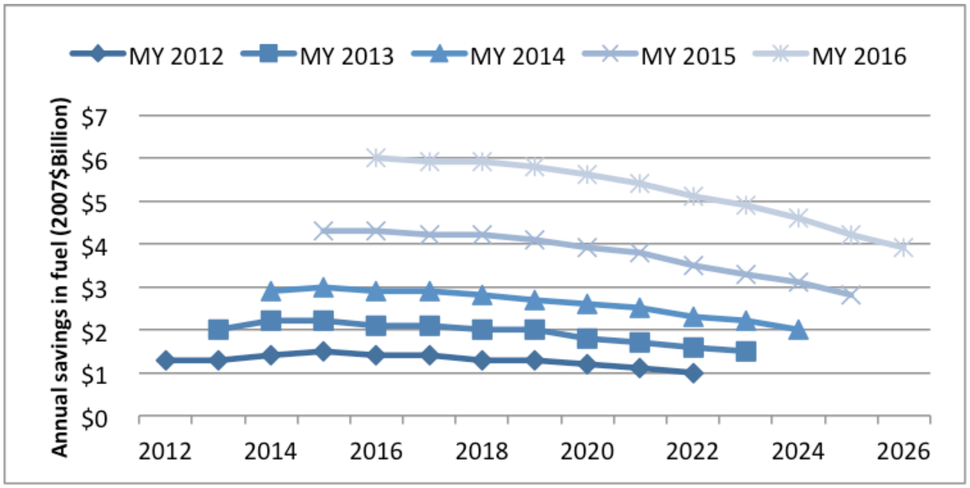

Figure 0-2. Annual savings in fuel expenditures achieved by new vehicle cohorts over ten years (Data source: EPA, 2010)

Aggregating the savings delivered by successive cohorts of new vehicles starting on 2012 result in total savings as shown in Figure 0-3.

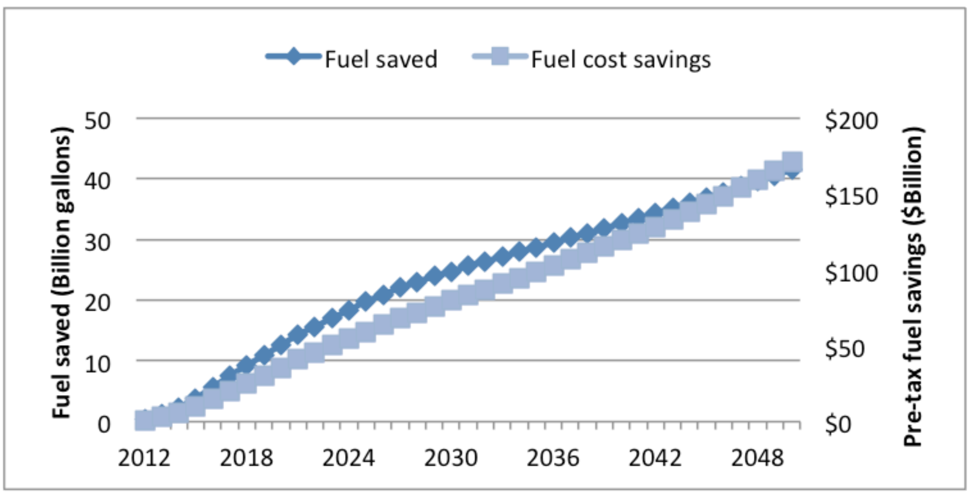

Figure 0-3. Aggregate fuel and fuel expenditure savings resulting from the National Program (Data source: EPA, 2010)

EPA's analysis finds that expenditure savings surpass compliance costs early into the program, yielding, in the balance, net savings. Table 0-7 shows the net present values of cost of compliance and fuel savings, using discount rates of three and seven percent.

Table 0-7. Total net present value of the cost to industry of meeting the 2012-2016 standards, estimated over the 2012-2050 timeframe

Discount rate	Passenger cars $Billion	Light duty trucks $Billion	Total $Billion	Fuel savings $Billion
3%	$226.73	$119.20	$345.94	$1,746.50
7%	$124.01	$67.85	$191.86	$778.34

Data source: EPA (2010)

The reader may notice that we emphasize the discussion of the rule for the 2012-2016 period. We do this to simplify the discussion and reduce the exposition of results with higher technological uncertainty.

In EPA's estimation, the cost of the program would be of $100 and $50 per ton of CO_2e, by 2020 and 2030, respectively, when only the costs to industry are factored in. Once fuel savings are also accounted for, the estimated costs become savings of $130 and $220 per ton of CO_2e, by 2020 and 2030, respectively.

The extent to which consumers factor into their purchase decisions the expected savings in operation costs resulting from fuel economy improvements is still matter of research. The general finding in the economic literature is that consumers are willing to pay less than one dollar for each dollar in discounted reductions of operation costs—a phenomenon known as the *energy paradox*[4] (Jaffe and Stavins, 1994). The energy paradox has been one of the central tenets of arguments in support fuel economy standards as a better strategy than fuel pricing to reduce fuel consumption (Greene, 1997). Some studies find evidence of an energy-paradox effect in consumer valuation of fuel economy (Allcott and Wozny, 2010), while for others (Bento, Li and Roth, 2012) the energy paradox may be more the result of the modeling approach chosen by analysts. Literature reviews (e.g. Helfand and Wolverton, 2009) reveal that studies have found evidence both of consumer undervaluation, overvaluation, and "about right" valuation of fuel economy. In its analysis, EPA chooses to assume that consumers *will* factor in the fuel savings over the first five years of their vehicle ownership and finds that the implementation of the National Program will result in higher new vehicle sales (EPA, 2010).[5]

[4] In more recent studies, this phenomenon has often been referred to *consumer myopia*.
[5] In their analysis of the 2017-2025 rule, EPA revised its perspective on this question and recognized that the scientific evidence is yet not definitive.

For the analysis of benefits and cost of government programs, the geographical scope is typically constrained to the jurisdiction or jurisdictions implementing the program. However, it should be noted that there was a clear leadership component to the adoption of AB 1493 by the state of California, which made the estimation of cost effectiveness less obvious. The state expected or hoped that similar programs would be adopted by other states and eventually by the federal government. If and as this policy diffusion happened, the scope of benefits would increase significantly while the per-vehicle cost would decrease following economies of scale. Thus, cost effectiveness for programs of these characteristics is better assessed if separated into short- and long-term.

For the National Program, EPA monetized the benefits of CO_2 emissions reductions. EPA started by adopting a range of values for the social cost of carbon (SCC) and two different discount rates: three and seven percent.[6] The SCC translates into dollar values estimates of the expected damages from emissions of carbon dioxide, such as changes in mortality, flooding from sea level rise, and many more. Needless to say, developing such estimates is a very complex process plagued with uncertainties, predominantly due to the fact that many effects are likely to be excluded and many other are non-quantifiable. What is certain is that the costs of carbon emissions are not zero. EPA (2010) used values for SCC of $5, $21, $35, and $65 in 2010. The first three values above represent mean values when the discount rate is taken as 5, 3 and 2.5 percent, respectively. The fourth value is the 95th percentile of the distribution, when the discount rate is taken as 3 percent, and is included to exemplify the impact of less likely, though possible catastrophic impacts. These values, developed through an interagency effort, represent the cost of increasing CO_2 emissions by one metric ton in 2010. Regardless of the initial value assumed for SCC, this value will increase over time, as the marginal impact of one additional ton of CO_2 will be higher with higher atmospheric concentrations.

The SCC values were subsequently updated by the interagency working group, reflecting improvements in the models on which they are based. Table 0-8 provides a summary of the SCC estimates in IWG SCC (2010) and IWG SCC (2013), showing that the update resulted in much higher values.

[6] Lower discount rates result in higher present values to costs and benefits occurring in the future.

Table 0-8. Social cost of carbon estimated in 2010 and revised in 2013 (Data source: IWG SCC, 2013)

Year	5% (mean) 2010	5% (mean) 2013	3% (mean) 2010	3% (mean) 2013	2.5% (mean) 2010	2.5% (mean) 2013	3% (95th percentile) 2010	3% (95th percentile) 2013
2010	4.7	11	21.4	33	35.1	52	64.9	90
2015	5.7	12	23.8	38	38.4	58	72.8	109
2020	6.8	12	26.3	43	41.7	65	80.7	129
2025	8.2	14	29.6	48	45.9	70	90.4	144
2030	9.7	16	32.8	52	50	76	100	159
2035	11.2	19	36	57	54.2	81	109.7	176
2040	12.7	21	39.2	62	58.4	87	119.3	192
2045	14.2	24	42.1	66	61.7	92	127.8	206
2050	15.7	27	44.9	71	65	98	136.2	221

Figure 0-4 shows estimates of the monetized social benefits that would result from emissions reductions from the program, for three different discount rates.

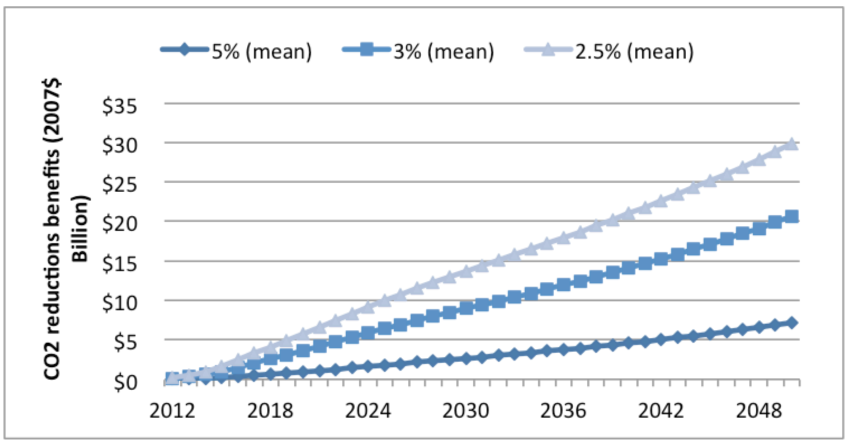

Figure 0-4. Mean social benefits of carbon emission savings for three different discount rates

Scalability and Transferability

The Pavley standards are a good example of a scalable and transferable program. Their adoption set the stage for a national debate about carbon emission standards from light-duty vehicles, which influenced the development of the National Program. Before voluntarily integrating with the National Program, the Pavley standards were adopted by a number of states. This adoption by other states was an extension of the adoption by the same states of the Low Emission Vehicle (LEV) program, statutorily enabled by Section 177 of the Clean Air Act. A longer discussion of this question is presented in the chapter on the Zero Emission Vehicle Program.

Technological Feasibility

According to the studies carried out by the agencies, meeting the standards for the 2012-2016 phase of the National Program can be accomplished with existing advanced technologies. This does not mean that the path toward compliance is free of challenges. Cheah and Heywood (2011) show that following the historical linear increase in fuel efficiency, even if all of these are used toward increasing fuel economy (ERFC equal 100%), may not be sufficient to meet the standards. Additional strategies in the design of new vehicles will be needed. Examples of such strategies include light weighting and vehicle hybridization.

For the 2017-2025 phase of the National Program, the agencies developed four technology pathways or scenarios to illustrate how the standards could be met by deploying combinations of proven technologies. Each scenario places emphasis on one or two technology strategies to increase fuel economy, as summarized in Table 0-3. Presenting various technology pathways reflects the diversity in strategies pursued by the car companies: some may emphasize hybridization, while others may emphasize advanced and diesel engines, and so forth. All the scenarios include significant reductions in net vehicle mass by MY 2025.

The mix of new vehicle drivetrains varies significantly depending on the technology pathway and the rate of increase in the stringency of the standards. If standards are increased at a rate of three percent per year, automakers may be able to meet them mostly using gasoline and diesel drivetrains, which may account for as much as 97 percent of the new vehicles in 2025. Automakers would not need to pursue vehicle electrification (PHEV or BEV) to meet this rate of increase in standards. Since the Advanced Clean Cars program integrates the former Pavley emissions standards with the Zero Emission Vehicle program, however, a scenario with no vehicle electrification would not be practicable in California and the Section 177 states.

When standards increase at a rate of six percent per year, on the other hand, the share of gasoline and diesel drivetrains may decrease to somewhere between 23 and 53 percent, depending on the technology pathway. Meeting standards at this higher rate of increase would need of vehicle electrification, the market share of which could range between four and 16 percent by MY 2025, depending on the technology pathway.

Administrative Burden

As described in earlier sections, the implementation of the National Program is a complex process, involving extensive procurement of technical information, analysis and often-arduous rulemaking processes in the face of industry opposition. Data collection and analysis are a critical part of the agencies' efforts to determine the cost-effective levels at which to set standards. This procedural burden is often a feature of command-and-control regulatory programs characterized by asymmetric information.

The implementation of the National Program also entails significant interagency coordination, which adds to the administrative burden in the short term, but will reduce it in the longer term as three different programs (California's, CAFE, and EPA's) are fused into one. The conditions under which California joined the National Program include securing commitments from the car companies that no challenge to new standards will be filed in the courts, which is expected to reduce administrative costs related to litigation.

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The Zero Emission Vehicle Program

Gustavo Collantes and Chuck Shulock

Highlights

- The Zero Emission Vehicle (ZEV) program is a long-term regulation that encourages innovation on technologies that produce no tailpipe emissions
- The ZEV program remains the main driver for the auto industry to commercialize zero emission vehicle platforms
- As shown in Figure 0-1, the cumulative number of vehicles produced toward compliance with the ZEV regulation is expected to approach 1.5 million by 2025 under the assumed main compliance scenario.

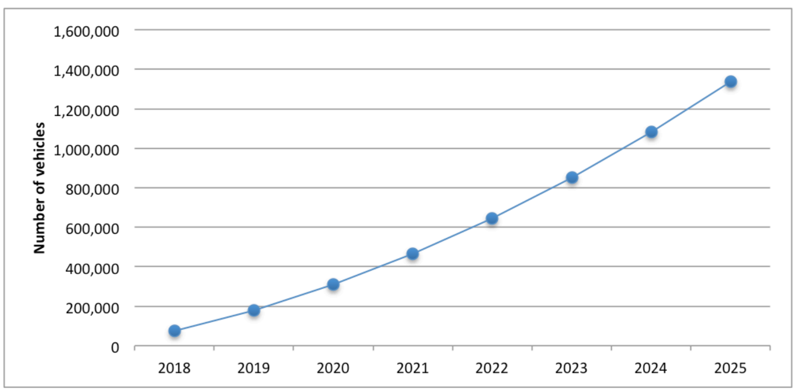

Figure 0-1. Cumulative numbers of vehicles produced toward compliance with the ZEV regulation, 2018-2025 timeframe

- The ZEV program has been adopted and remains effective in the District of Columbia and 10 states, in addition to California
- Growing the market for zero emission vehicles will require strong public-private partnerships, policies and investments that complement the ZEV regulation
- The ZEV regulation has been and will continue to be revised to incorporate new information about technological progress, and to adopt new credit structures to more effectively support this progress
- There is a need for better data to support the research and analysis of effective and equitable strategies for the market adoption of zero emission vehicles

Background

On September 28, 1990, the California Air Resources Board approved the Low Emission Vehicle and Clean Fuels program (LEV program) with resolution 90-58. The program, which put in place the Zero Emission Vehicle (ZEV) requirement as well as stringent fleet average tailpipe standards for conventional vehicles, was coded into Title 13, California Code of Regulations (CCR). The original ZEV regulatory language was simple: "While meeting the fleet average requirement, each manufacturer's sales fleet of passenger cars and light-duty trucks from 0 to 3750 lbs LVW, shall be composed of at least 2% ZEVs each model year from 1998 through 2000, 5% ZEVs in 2001 and 2002, and 10% ZEVs in 2003 and subsequent model years" (CARB, 1990, p.22).

The primary policy goal of the ZEV program has historically been to improve air quality by reducing emissions of criteria pollutants. With Resolution 08-24, dated March 2008, the California Air Resources Board broadened the focus of the ZEV program to also serve as a greenhouse gas reduction strategy that would help the state meet its long-term carbon emissions reductions goals, as specified by the Global Warming Solutions Act of 2006 (AB 32).

In its original form the ZEV mandate only dealt with "pure" zero emission vehicles. As manufacturers began to explore the potential for electric drive to improve the operation of conventional internal combustion engine vehicles, CARB staff recognized that increased sales of hybrid electric vehicles would expand the market for batteries, power control electronics, motors and related equipment, thus lowering their cost and aiding the transition to pure ZEVs. In response the mandate was expanded to provide partial credit for the use of "ZEV-enabling" componentry. Next, plug-in hybrids were recognized as a valuable approach that provided significant zero emission operation but also had the capability for extended range when needed, and were awarded additional partial credit. But the regulation still maintained a bright line between vehicles with and without a tailpipe. Most recently, however, the BEVx category was added to provide pure ZEV credit for vehicles with a "limp-home" internal combustion engine, blurring for the first time the distinction between pure ZEVs and other platforms. Recognizing that in the current state of technology the number of electric vehicle miles traveled (eVMT) for some plug-in hybrid or BEVx may be comparable to those of some pure BEVs (which in the early stage of market development are characterized for example by vehicle range typically under 100 miles), at its January 2012 hearing the board directed staff to return to the Board with in-use data for range extended battery electric vehicles and plug-in hybrid electric vehicles, and, if warranted, propose appropriate modifications to treatment and credits for these vehicle types in 2016. Further research is needed to understand the behavioral or structural reasons for the mileage observed for each technology platform, but regulators need to find a balanced solution that does not inadvertently result in encouraging higher vehicle miles traveled.

Another critical evolution affecting the ZEV program is that it has become increasingly immersed in a complementary array of programs, policies and policy directions at the state and local levels, which help create environments conducive to ZEV market adoption. In other words, it became increasingly understood that the ZEV program cannot succeed purely as a mandate upon industry, and that complementary approaches including partnerships, are absolutely essential. As a consequence, the state implemented programs such as financial and non-monetary incentives, deployment of charging infrastructure, plug-in electric vehicle readiness plans, and other policy directives.

A very important piece of the state's support for ZEVs occurred on March 23, 2012, when Governor Brown signed Executive Order B-16-2012 directing the state to "support and facilitate the rapid commercialization of zero emission vehicles." The directive in EO B-16-2012 that received the most publicity is to meet a goal of 1.5 million zero emission vehicles in California's roads by the year 2025, consistent with the requirements of the ZEV regulation. The Executive Order includes a timeline with a broad set of directives that support zero emission vehicles in a holistic manner. We summarize this timeline in Table 0-1.

Table 0-1 Chronology of directives in the Governor's Executive Order B-16-2012

	2015	2020	2025
Process	CARB, CEC, CPUC collaborate with PEVC and CaFCP.		
Vehicles	ZEVs are 10% of state LDV purchases.	Cost competitive with conventional. Widespread use in public transport and freight.	1.5 million ZEVs on the state roads and growing. ZEVs are 20% of state LDV purchases.
Climate goals		ZEVs have tangible impact on state carbon emissions.	
Infrastructure	Major metropolitan areas adopt plans. Growing private investment.	Capable of supporting one million ZEVs.	Easy access to all Californians.
Electricity		EV charging integrated into the grid.	
Research	State's academic institutions contributing to research, innovation and education.		
Manufacturing	Expanding in-state vehicle and component manufacturing.	Expanding role of CA private sector in ZEV supply chain.	ZEV industry is a strong part of the state's economy.

The category of vehicles known as zero emission vehicles is defined as vehicles that produce zero exhaust emissions of any criteria pollutant (or precursor pollutant) under any and all possible operational modes and conditions (Title 13 CCR §1962 (a) 1.1). The technologies available today that meet this definition are battery electric vehicles and hydrogen fuel cell vehicles. Recognizing, however, that in the near term zero-emission vehicles face cost, performance and customer acceptance barriers, over time the ZEV regulation has been modified to allow manufacturers to satisfy part of their obligation with other vehicle types that feature extremely low emissions, with additional compliance credit given to vehicles that employ "ZEV-enabling" technologies such as electric drive. From a policy perspective, the Air Resources Board basically traded off a reduction in the number of required "true zero" vehicles in order to get large numbers of extremely clean advanced conventional vehicles.

At this point, we introduce summary definitions of the relevant vehicle technology categories created for the purpose of the current ZEV regulation. The complete definitions are rather long and we refer the reader to Title 13 of the California Code of Regulations, Section 1962 for the details. Essentially, each of these categories, in the order presented, comprise vehicles that deliver increasing zero-emission functionality.

- PZEV stands for Partial Zero Emission Vehicle. To qualify as a PZEV a vehicle must meet the most stringent tailpipe standards, have zero evaporative emissions, and offer an extended 150,000 mile warranty on all emission-related components (CARB, 2009, p. B-4).
- AT PZEV stands for Advanced Technology Partial Zero Emission Vehicle. An AT PZEV must meet all PZEV criteria plus make and must also feature electric drive (for example, as in hybrid electric vehicles) or gaseous fuel storage (for example, as in compressed natural gas vehicles) (CARB, 2009, p. A/B-1).
- TZEV stands for Transitional Zero Emission Vehicle. This category was formerly known as Enhanced AT PZEV and refers to a vehicle that has at least 10 miles of zero emission range, such as in all plug-in hybrid electric vehicle (PHEV) models currently offered in the market (CARB, 2009, p. B-3).
- ZEV stands for Zero Emission Vehicle and refers to "any vehicle certified to zero emission standards" (CARB, 2009, p. B-4). For the regulation, not all ZEVs are equal. Depending on their range and their fast charging capabilities, they may earn different numbers of credits toward compliance.

The ZEV program has now become an integral part of the Advanced Clean Cars program, which combines previously separate regulations into one package that regulates criteria pollutant and carbon emissions from mobile sources and also imposes the requirement for zero emission vehicles.

The ZEV obligation on its face is expressed in terms of the number of ZEV credits that must be earned by manufacturers. Figure 0-2 shows the ZEV credit requirements on large-volume manufacturers[7]. Thus, for example, in 2025 manufacturers must earn credits from TZEVs for up to 6 percent of sales, and credits from ZEVs for at least 16 percent of sales, for a total ZEV credit obligation equal to 22 percent of sales.

[7] The minimum requirements apply to vehicles produced by the regulated manufacturer and delivered for sale.

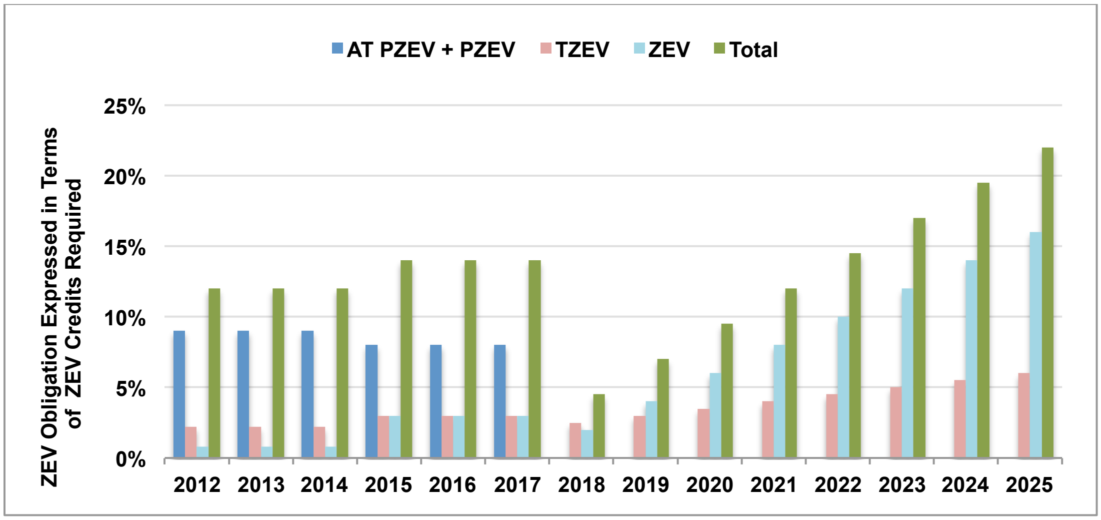

Figure 0-2. Total ZEV requirements, minimum percentage of pure ZEVs and maximum percentage that can be covered with credits from other technologies

As Figure 0-2 shows, for model years 2012 through 2017 manufacturers can meet their ZEV requirements using combinations of ZEVs, credits, TZEVs, AT PZEVs and PZEVs, with prescribed maxima for the last four. Beginning in 2018 PZEVs and AT PZEVs will no longer count towards compliance (the rationale is that such vehicles are considered to be becoming fully commercialized and thus will no longer need to be incentivized via the ZEV program). From that point forward the entire obligation must be met with TZEVs and ZEVs.

The total requirements for 2017 reach 14% of the new vehicle fleet while in 2018 the requirement falls to 4.5%. The difference is that until 2017 manufacturers are allowed to meet most of the requirements with vehicles that do not actually have the capability of delivering significant zero-emission mileage (including very clean conventional vehicles and hybrid electric vehicles). Starting in 2018, requirements can be met only with pure ZEVs (battery electric vehicles and/or hydrogen fuel cell vehicles) or Transitional Zero Emission Vehicles (TZEVs), which deliver some zero-emission mileage. Figure 0-3 and **Error! Reference source not found.**Figure 0-4 show compliance scenarios with the maximum fraction of non-ZEV vehicles that automakers could adopt for compliance with the program in the 2012-2014 and 2015-2017 periods, respectively.

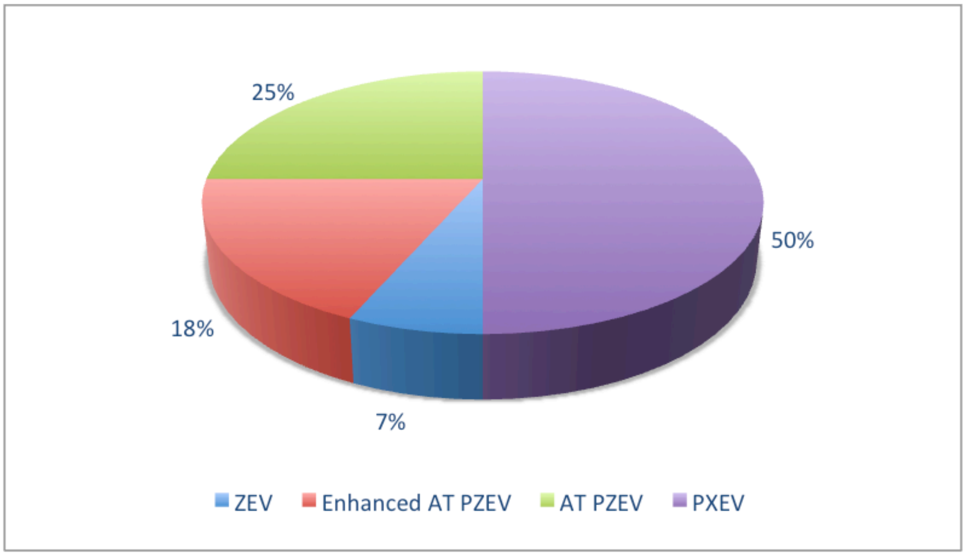

Figure 0-3 Maximum shares of the 12% ZEV requirement in 2012-2014 that can be met with PZEV not PXEV

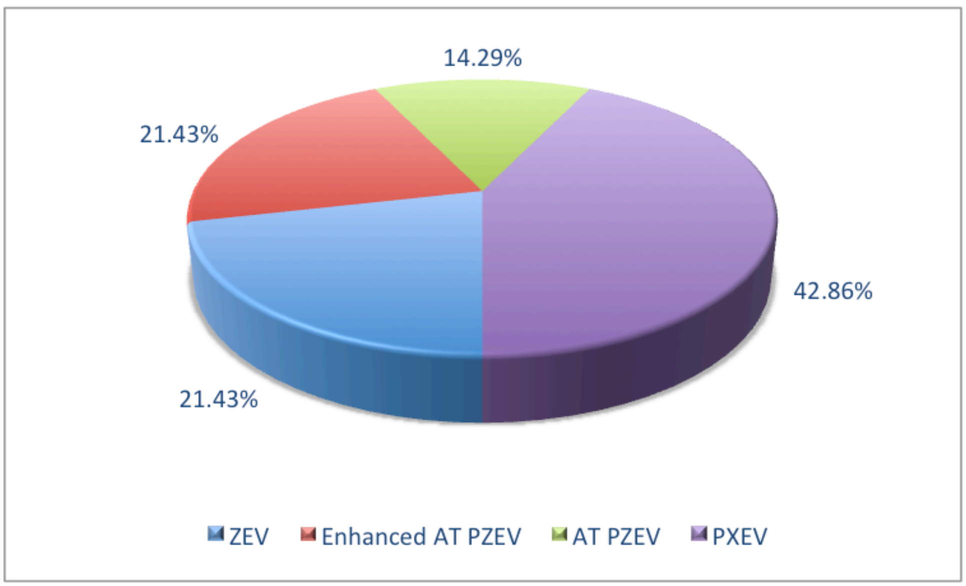

Figure 0-4 Maximum shares of the 14% ZEV requirement in 2015-2017 that can be met with PZEV not PXEV

As noted above, however, different types of vehicles earn different amount of ZEV. For example in the 2016-2017 period a BEV will earn about 3 credits, a fuel cell vehicle about 9 credits, and a PHEV less than 1 credit. Thus it is also instructive to look at the ZEV obligation in terms of the number of vehicles that manufacturers will produce to meet the obligation, as opposed to the number of credits that they must earn. Figure 0-5 below shows the 2018-2025 ZEV obligation for large volume manufacturers expressed in terms of the number of vehicles of sales of each vehicle type. The ZEV regulation provides considerable flexibility to manufacturers so there are a variety of compliance scenarios. Figure 0-3 is based on the standard CARB assumptions regarding future manufacturer behavior.

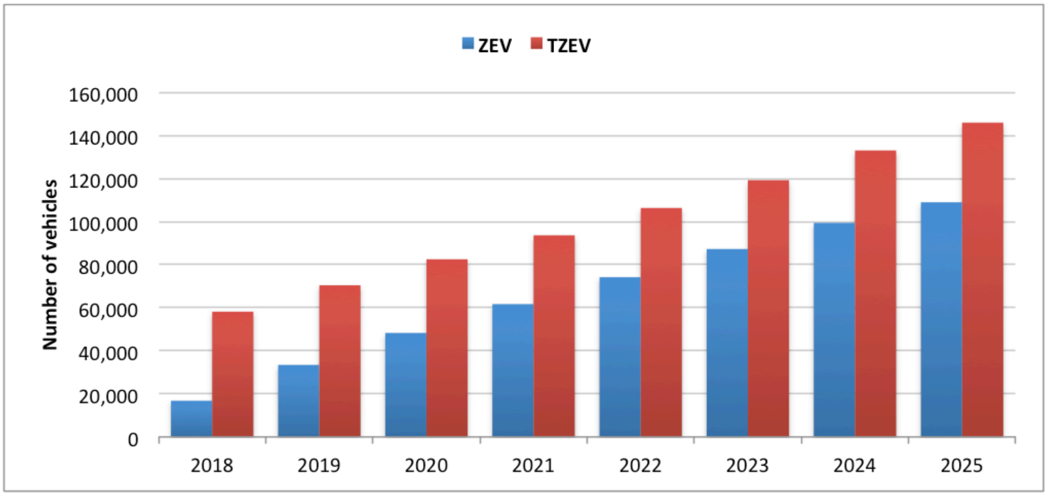

Figure 0-5 Total ZEV requirements in numbers of vehicles from 2018 to 2025

As Figure 0-5 shows, in 2025 manufacturers are expected to produce about 109,000 ZEVs (roughly 6% of total sales) and about 146,000 TZEVs (roughly 8% of total sales).

Historically, ZEV requirements applied to passenger cars and smaller light-duty trucks (known as LDT1). Since model year 2009, regulated manufacturers have been required to include increasing percentages of their larger light-duty truck (LDT2) production in the calculation of their ZEV requirement. As of model year 2012, all LDT2s are to be included in this calculation.

Cost Effectiveness

Doing a fair assessment of the cost-effectiveness of the ZEV program is not a trivial endeavor. Clearly, it could not be done using the exact same metrics that would commonly be used for mature technologies. ZEVs continue to be, after 24 years of the program, a disruptive technology or alternatively a radical innovation, while improvements in conventional technologies are generally achieved by incremental innovation. The marginal costs of radical and incremental innovations are not comparable. A key driver for the mandate is that even though the private cost of ZEVs can be quite high in the early years, as technologies improve and production levels ramp up they will offer a competitive value proposition to increasingly larger segments of consumers.

There is support for this viewpoint. Greene, Park and Liu (2013), based on related work performed by the National Research Council (NRC 2013), have projected that after 2040 BEVs and FCEVs become less costly than comparable ICEs or HEVs. They go on to argue that this eventual cost advantage means that while the costs of inducing a transition to electric drive transportation in the United States could be very large, the private and social benefits could exceed these costs by an order of magnitude. However, as the authors point out, significant uncertainties still remain around the progress of relevant technologies and the market acceptance of electric drive vehicles. Indeed, studies in the past have offered optimistic conclusions about the technological and market progress of zero emission vehicles (for example, Delucchi, etc.). Reducing these uncertainties will require continued research on technology, policy and markets. We add that not only do uncertainties affect these variables, but also a host of other factors related to the future of transportation. For example, fuel markets have historically exhibited high volatility and jumps, which translate in uncertain projections for the economics of conventional vehicles (e.g. Burke, Collantes, and Miller, 2014).

The assessment of cost effectiveness also needs to be preceded by an assessment of the benefits, for which scope and time scale have to be defined. While federal guidelines for cost-benefit analysis recommend including only benefits accrued in the jurisdiction where the regulation is implemented, a strong argument can be made against this guideline for the case of ZEVs, and in general for every program with implications for climate change.

Scale of Potential Emissions Reductions

Conceptually, the scale of the emission benefits that can be brought about by zero emission vehicles can be summarized as follows: ZEVs are a necessary component of any strategy that hopes to meet long-term carbon goals from road transportation at the state, federal and global levels. Simply put, passenger vehicles will not be able to achieve an 80% GHG reduction (the 2050 target in California as well as in other jurisdictions) using hydrocarbon fuels. Electric drivetrains are needed to approach this goal.

This statement should be understood as implying a parallel strategy to reduce the carbon footprint of electricity generation and hydrogen production. ZEVs however can integrate with the process of fuel production in ways that conventional cars cannot, and can contribute to the integration of renewable sources of energy. Thus the growth of ZEV markets can produce double wins by reducing emissions both from mobile carbon (displacing fossil fuels) as well as from electricity generation (helping to integrate renewable energy).

Scenario analyses conducted by CARB support the notion that ZEV are essential to achieve 80% reductions in carbon emissions by 2050, and further suggest that hydrogen fuel cell, full electric, and plug-in hybrid electric vehicles will all be needed (CARB, 2009). CARB's analysis includes two scenarios. Both share a set of basic assumptions, including:

a- VMT will decline by 20% to 9,600 miles per year per vehicle (while total state VMT continues to grow due to population growth) as a consequence of the implementation of strategies that promote mass transit, urban design, car sharing, and others;
b- The carbon intensity of the state's electricity falls dramatically from 121 gCO2e/MJ in 2009 to 29 gCO_2e/MJ in 2050, by increasing the share of conventional renewables to 40% while maintaining the share of large hydro at 20%.

The two scenarios differ in the assumptions regarding the rate of market penetration of ZEVs, as follows:

- Scenario 1 assumes that annual ZEV sales reach 25,000 in 2020 and 230,000 in 2025, while the cumulative number of ZEVs on the road reaches 100,000 in 2020 and 900,000 in 2025. Under this scenario, GHG emissions reductions decline by 66%, thus not meeting the 80% goal.
- Scenario 2 assumes that annual ZEV sales reach 25,000 in 2020 and 425,000 in 2025, while the cumulative number of ZEVs on the road reaches 120,000 in 2020 and 1.4 million in 2025. Additionally, this scenario assumes that over one million of cumulative sales of PHEVs are attained by 2025. Under this scenario, GHG emissions reductions decline by 73%, again not meeting the 80% goal. CARB also prepared a variant of scenario 2 in which additional volumes of low carbon biofuels are blended into petroleum fuels. In this variant, the 80% emissions reductions objective is met.

In a sequence of scenario analyses (Yang, McCollum, McCarthy, and Leighty, 2009; Leighty, Ogden and Yang, 2012), researchers at UC Davis explored combinations of strategies that could make the goal of reducing emissions by 80% by 2050 possible. They find that achieving this goal in the light-duty vehicle sector may be technologically feasible contingent on aggressive assumptions on technology progress and other factors. The common theme in all scenarios is the need for electric drive, zero emission vehicles in significant numbers. Most of the supply of low carbon biofuels will be needed to lower the carbon intensity of other segments of the transportation sector (for example, freight, marine and aviation), and will not be available in great volumes for the light-duty sector. Thus, zero emission vehicles take a leading role in achieving deep reductions in emissions from the light-duty vehicle segment. Other recent research has come to similar conclusions. One study for California concludes that "there was no alternative to widespread switching of direct fuel uses (e.g., gasoline in cars) to electricity in order to achieve the [80% by 2050] reduction target" (Williams et al., 2012).

Scenario analyses of these types are useful to gain understanding of what is needed technologically to achieve the carbon emission goals. They do not help much with understanding the market dynamics of these technologies, in particular the extent to which consumers will accept them and under what conditions. These dynamics are embedded in the scenario as assumptions (i.e. they are taken as exogenous variables). Ross Morrow, Gallagher, Collantes, and Lee (2010) model the effects of different sets of strategies or "policy packages" to induce innovation and market behavior to reduce carbon emissions from the light-duty vehicle segment. They find that very aggressive strategies, some of which may prove politically difficult to implement or even bring to the political agenda, make relatively small progress to curb carbon emissions. While such economic models allow for market dynamics to manifest themselves (i.e. they are endogenous to the model), they still suffer from limitations. For example, consumer reaction to transformative vehicle technology is not yet fully understood and thus there is great uncertainty about the robustness of some of the economic parameters used in the models, such as elasticity of demand with respect to vehicle fuel economy or vehicle range. Also, these models still need a large number of assumptions regarding technology progress, such as the evolution in the price per unit of energy of low-carbon biofuels or the price per kilowatt of fuel cells. Greene et al. (2013) speak to the sheer magnitude of the uncertainties involved when analyzing the transition to electric drive transportation and to the need for adaptive policies that can improve the chances for a sustainable ZEV market to flourish.

Lutsey and Sperling (2012) note that assigning plug-in vehicles an emission factor of 0 grams per mile when they operate on electricity (as is done in the 2017-2022 period of the National Program) forgoes an opportunity to further the carbon emission benefits of regulatory programs. As discussed in the Advanced Clean Cars chapter, regulatory agencies have not come to an agreement on how to treat the upstream emissions associated with electricity generation and hydrogen production. This is a complex area for policy where more research and analysis is needed.

Finally, the ZEV program offers climate benefits through its impact on non-carbon emissions. Toxic and criteria pollutant emissions from mobile sources also have short-term climatic impacts (Shindell, et al., 2011), which are often neglected in climate policy discussions and related analyses.

Scalability and Transferability

Section 177 of the U.S. Clean Air Act (CAA, 42 U.S. Code §7597) grants any state the right to adopt and enforce emissions standards on new motor vehicles that are identical to the California standards, provided that California has obtained a waiver from the U.S. Environmental Protection Agency, per Section 209 of the CAA. The ZEV program has been adopted by a number of states over the years. Besides California, the program is currently active in the District of Columbia and 10 states: Connecticut, Maine, Maryland, Massachusetts, New York, New Jersey, Oregon, Rhode Island and Vermont. Taken together, these states comprise about 25% of the new vehicle market in the United States.

Thus, the CAA provides the legal framework for air quality programs borne in California to scale out and be transferred to other states. California has developed, over decades, the institutional infrastructure that provides, directly or indirectly, support to other states in their implementation processes. Specifically, the design, review, analysis, and revision of environmental programs such as those under the AB 32 umbrella can be administratively burdensome and technically very complex. The State of California, especially through the Air Resources Board and the Energy Commission, provide the investments, analysis, and policy processes upon which other states often build their implementation processes.

The transferability of the ZEV program is of tremendous benefit to the goals of the program. The market development of transformational technologies such as zero emission vehicles is better assisted with compliance flexibility and eventually with high production volumes. The "travel" provisions included in the program, which allow manufacturers to count vehicles sold in other states toward compliance with the program, gives the auto industry discretion to pursue a wider range of commercialization strategies by targeting markets in multiple geographies (or conversely, by focusing sales efforts in locations with supportive infrastructure), thus adding flexibility to the program. The confluence of many states under the program provides a much larger consumer base with correspondingly larger latent demand for ZEVs. To the extent that the states help provide the conditions for consumer acceptance (for example by investing in well-planned charging and refueling infrastructure, providing financial and/or non-financial incentives based on market analysis, etc.) this larger consumer base should help the industry, when technologies are ready, to increase production volumes toward sustainable markets.

Technological Feasibility

The discussion included earlier in the section Scale of Potential Emissions Reductions is largely relevant to the question of technological feasibility. The state is finally witnessing an incipient plug-in vehicle market, growing to about 3% of new vehicle sales. All of the large manufacturers are offering plug-in models and some have started plans to commercialize hydrogen fuel cell vehicles. Plug-in vehicles currently in the market, such as the Nissan Leaf, the Chevy Volt, and the Tesla Model S, are great technological achievements and continue to obtain high levels of consumer satisfaction. Hydrogen fuel cell vehicles continue to exhibit remarkable progress on all needed areas, including onboard hydrogen storage and fuel cell stack reliability and cost (Ogden et al., 2014) These are encouraging signs that speak to the advances made by industry in technology development through investments, research and testing.

However, the question of technological feasibility, understood as inclusive of market viability, is not fully answered yet. The ZEV program was adopted in 1990, which means that industry has been under regulatory pressure to develop and commercialize zero emission vehicles for almost 24 years. The perception of incipient electric vehicle markets is not new and many studies in the past erred on optimism. It is important to recognize this context and incorporate it into policy, planning and research over the next years. As noted in Greene et al. (2013) policy should be adaptive. Research should continue identifying gaps and gaining understanding of market dynamics. Policy, planning and advocacy should be informed by the latest research to promote the efficient functioning of the innovation system. Collantes (2008) discusses how the policy process, involving the interaction of all relevant stakeholders and resulting in strategic choices by them, directly influences technological progress. Information is a central determinant of stakeholders' policy beliefs, which in turn directly affect the strategic choices they make, such as investments, program development, etc. The effectiveness and efficiency of these strategic choices in fostering technology progress is intimately related to whether they are grounded on solid information (for example, research, experience, etc.).

Zero emission vehicles are transformative innovations that break away from many of the molds developed over many decades around petroleum-fueled vehicles. For a host of reasons, this is not easy to do. This transformation is not only technological; it also affects, and depends on, institutions, market dynamics and social norms. As a consequence, the "feasibility" of zero-emission technologies in general, and of the Zero Emission Vehicle program in particular, cannot be assessed using only the lens of technological progress—a system perspective is more appropriate. For example, technology feasibility will require that elected officials and regulators take the necessary steps to enable the transformation. Technology feasibility will also require the key economic institutions—auto industry, electric utilities, new car dealers—to reach a tipping point of sustainable commitment to the transformation. Observers, and in particular policymakers, need to be patient and even-tempered. The transition to electric drive, while necessary to meet long-term climate goals, will take decades to be fully realized. There will inevitably be fits and starts along the way. But in the meantime it is clear that if stakeholders and policymakers want to continue to foster a transition to electric drive they will need to muster the fortitude to avoid over-hyping near-term successes and over-reacting to near term challenges.

Administrative Burden

As described above, the ZEV program started as a simple mandate that required that specific percentages of the vehicles produced and sold by large manufacturers be zero emission. The entire program description fit in one page. Since its inception, the ZEV program grew exponentially in complexity, starting in 1996. This growth in complexity is a reflection of the efforts of CARB to adapt the regulation to the realities of technology progress and a policy learning process that is expected when there are no precedents to build upon or learn from (Collantes, 2006). Moreover, manufacturers have different views as to what type of vehicle will meet with market success, and CARB has tried over the years to provide flexibility to manufacturers rather than having the regulation choose "winners". This increased flexibility translates into increased regulatory complexity.

The capability to adapt is in itself a positive quality of policy. Certainly, the revision path taken by the ZEV program is the result of a collaborative process between CARB and stakeholders, particularly the car industry (Collantes, 2006). Adaptation and complexity do not however need to always go hand in hand. The revision path increased the policy and administrative complexity of the program to, it can be argued, excessive levels. It is not easy to draw a theoretical line beyond which program complexity becomes excessive, but there are general guidelines that could be considered. For example, program simplification could be made an integral part of the program development process so that, all else equal, simpler policies are preferred over complex ones.

Distributional Effects

At present the incremental cost to large manufacturers of producing zero emission vehicles is being passed on to a base of consumers broader than those who actually buy ZEVs. This will be so as long as automakers can only sell ZEVs at a loss (i.e. the per-vehicle cost of supply is higher than the price that consumers are willing to pay) and they recover that loss by marginally increasing the price of new conventional vehicles (e.g. Gruenspecht, 2001). In addition, at present ZEV buyers have a higher average income than the population at large. Clearly, distributional impacts of policy need to be carefully evaluated. This particular concern, however, will not have a large impact on the cost of other vehicles insofar as the regulation adapts according to the realities of technology costs. While technology costs are high, volume requirements will remain low and any cost spread across consumers will remain nominal. But more importantly, the excess cost of ZEVs is not meant to provide a private benefit to ZEV owners, in which case spreading the cost across consumers would be open to question on equity grounds. The excess cost is instead meant to pay for social benefits (e.g. air quality, carbon emissions mitigation, long-term energy security, etc.). By definition, these are benefits enjoyed not only by ZEV owners, or not even only by all prospective consumers, but by the general population.

Further Work

CARB has repeatedly modified the ZEV regulation as new information emerged regarding the pace of technology development, the perceived difficulty of various compliance pathways, and customer response to competing vehicle technologies. There are several areas where additional research and analysis could inform possible additional needed modifications. We mention just a few here.

The first involves the regulatory treatment of vehicles that have a tailpipe. As discussed above, CARB staff is investigating how the vehicle-miles traveled on electricity, or “eVMT”, by PHEV and BEVx compare to those of pure ZEV, and whether such metric would be adequate for changing the treatment of credits within the regulation. In other words, the question of interest is whether eVMT would be an adequate metric to decide the credits that each vehicle type or model will receive toward compliance with the ZEV regulation. This is a complex question that needs careful study and the answer to which will depend not only on high quality data and quantitative analysis, but also on a policy discussion. Whether this study will have evolved sufficiently to inform a discussion of the eVMT question in time for the midterm review is still uncertain.

It is critical that discussions about modifications to the regulation recognize the importance of regulatory certainty and consistent regulatory directions. The regulated industry makes strategic decisions on multi-year time horizons, for which they take into account, among myriad other elements, the direction set by the program. The strategic production direction taken by certain companies was likely directly influenced by the structure of the ZEV program, and future modifications must take this into consideration.

Another fruitful area would address the relative "value" assigned to plug-in versus fuel cell vehicles for purposes of regulatory compliance. Although in principle the regulation has always been intended to provide a level playing field for competing technologies, in practice the crediting schemes have been calibrated and re-calibrated over time to (a) ensure that manufacturers who wanted to pursue any technology strategy, such as hydrogen fuel-cell or plug-in electric, could have a viable compliance path (consistent with the technology-neutral approach of the program), and (b) provide that each strategy demands a similar "level of effort" from manufacturers. The underlying objective has been to ensure that the regulation remained technology neutral and did not unintentionally favor any one technology.[8] In its present form the regulation provides, taking into account the combined impact of the several provisions, substantial additional credit for hydrogen fuel cell vehicles based on an understanding that their early rollout would be more difficult and expensive. Again, as new information is being gained regarding manufacturer strategies, technology development, the in-use behavior of drivers, their charging and refueling strategies and the availability of infrastructure, it is important to continue evaluating the assumptions underlying the program.

Finally, other regulations such as the Low Carbon Fuel Standard, the AB 1493 passenger vehicle greenhouse gas regulation (Pavley and the National Program), the Renewable Portfolio Standard and the cap and trade program also have an influence on the relative treatment of battery and fuel cell vehicles. Where relevant these other regulations should be taken into account when assessing the combined impact of the entire set of incentives faced by vehicle manufacturers, and research is needed to better understand their interaction.

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[8] This philosophy on the part of the Board has manifested itself in various adjustments over time to the travel provision as well as in the credit given for vehicle range and refueling

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The Sustainable Communities and Climate Protection Act (SB 375)

Gustavo Collantes, Rod Brown and Anthony Eggert

Key Findings

Policy description

- SB 375 directs metropolitan planning organizations (MPOs) to prepare sustainable communities strategies (SCSs)
- The goal of SCSs as currently adopted is to, once integrated with other policies, attain reductions in greenhouse gas emissions from transportation of up to 8% by 2020 and up to 16% by 2035, depending on the MPO
- SB 375 has created an important institutional signal to explicitly account for carbon emissions in regional land-use and transportation planning
- It has been demonstrated that land use planning and other tools can help reduce vehicle miles traveled (VMT), but predicting the aggregate reduction and how it will translate into reductions of greenhouse gases is difficult. More research should be directed to this area.
- As a consequence, even when MPOs project that they will meet or exceed their respective targets, these projections suffer from critical uncertainties
- The large scale transformation of prevalent land use patterns into forms more conducive of alternative transportation will take decades
- The main weakness of SB 375 is that it does not have a mechanism to enforce the implementation of SCSs, which is ultimately left to local governments
- Research should assess the need for complementary price signals that better reflect the external costs of car travel and land intensive developments, to change travel behavior and development practices
- Many local jurisdictions will need direct funding to update their general plans and zoning to align with SCSs

Background

With the passage of the Sustainable Communities and Climate Protection Act, Senate Bill 375 (SB 375, Steinberg) in 2008, the State of California explicitly recognized the connection between sustainable mobility, and in particular, reductions in carbon emissions from road transportation, and land use planning. SB 375 requires metropolitan planning organizations (MPOs) in California to adopt Sustainable Communities Strategies (SCSs) to achieve GHG emissions reductions from passenger vehicles. The bill directs CARB to set, in collaboration with the MPOs, emission reduction targets for each of these regions. Specifically, SB 375 states "*Each metropolitan planning organization shall prepare a sustainable communities strategy, including the requirement utilizing the most recent planning assumptions considering local general plans and other factors. The Sustainable Communities Strategy shall: (…)*

7- set forth a forecasted development pattern for the region, which, when integrated with the transportation network, and other transportation measures and policies, will reduce the greenhouse gas emissions from automobiles and light trucks to achieve, if there is a feasible way to do so, the greenhouse gas emission reduction targets approved by the (California Air Resources Board)". These SCSs will be integrated into the Regional Transportation Plan (RTP) of each region.

This chapter reports on the current status and prospects for success of SB 375, examines the evidence on the potential of reducing GHG emissions from VMT through land use and related strategies, and identifies obstacles to implementing sustainable communities strategies as well as possible actions to overcome such obstacles.

Scale of Potential Emissions Reductions

To establish targets for GHG emissions reductions for each of the 18 MPOs subject to SB 375, CARB appointed the Regional Targets Advisory Committee (RTAC). These MPOs, shown in Figure 0-1, cover 98% of California's population (*Regional Targets Advisory Committee Recommendations*, 2009). The final targets, shown in Table 0-1, were released in February 2011. Actions taken to comply with the program are expected to result in 8% of the reductions in transportation GHG emissions and 3% of the reductions in total California GHG emission expected by 2020 (Bedsworth, Hanak, & Kolko, 2011).

Figure 0-1 MPOs Subject to SB 375 (*Regional Targets Advisory Committee Recommendations*, 2009)

Table 0-1 Initial GHG Emission Reduction Targets, percent change per capita relative to 2005 (*Approved Regional Greenhouse Gas Emission Reduction Targets*, 2011)

Metropolitan Planning Organization	2020 Target	2035 Target
Southern California Association of Governments (SCAG)	-8%	-13%
San Francisco Bay Area Metropolitan Transportation Commission (MTC)	-7%	-15%
San Diego Association of Governments (SANDAG)	-7%	-13%
Sacramento Area Council of Governments (SACOG)	-7%	-16%
[San Joaquin Valley MPOs (eight total)	-5%	-10%
Tahoe Metropolitan Planning Organization (TMPO)	-7%	-5%
Shasta County Regional Transportation Planning Agency (SCRTPA)	0%	0%
Butte County Association of Governments (BCAG)	+1%	+1%
San Luis Obispo Council of Governments (SLOCOG)	-8%	-8%
Santa Barbara County Association of Governments (SBCAG)	0%	0%
Association of Monterey Bay Area Governments (AMBAG)	0%	-5%

The actual impact of SB 375 on carbon emissions will ultimately depend on two questions:

a- If implemented, what would be the impact of SCSs on carbon emissions relative to business as usual?

b- To what extent will local governments implement the policies and actions described or implied by the SCS?

The answers to these questions are complicated. MPO transportation models generally indicate that they will meet or even exceed the GHG goals assigned to them. The literature that we reviewed does not look specifically at the climate effects of SB 375 but rather looks at the effect of individual policies or groups of policies that could be or are being pursued to meet SB 375 goals. While more sustainable ways of development such as Smart Growth have received much attention, it is fair to say that Smart Growth is not necessarily equal to SCS and therefore more analysis is needed, particularly on if and how SCSs will be successful in the long term.

The Connection Between Types of Developments and Travel Behavior

The connection between the built environment and personal mobility is the area of study that has received the most attention in the urban planning literature (R. Ewing & Cervero, 2010). A central assumption behind SB 375 is that land use policy and urban design can significantly affect GHG emissions.

A few definitions

Land use planning/policy: the rules governing how parcels may be developed and employed.

Urban design: the arrangement of buildings, streets, biking and walking infrastructure, and public spaces.

Density: the number of residents, workers, buildings, or other features per unit area.

Intersection density: the number of road junctions per unit area.

The relationship between land use and urban design and personal mobility strongly depends on the type of destination (e.g. work trips, shopping trips, etc.) and the mode (e.g. personal automobile) considered. R. Ewing and Cervero (2001, 2010) conducted meta-analyses of these relationships.

It's not (just) about density

While it is a commonly held belief that urban density at the residential and at the workplace ends contributes to lower VMT, it was found that in general this influence is at best modest when other factors are controlled for. The majority of the studies appear to have failed to find a statistically significant correlation between density and VMT, and wherever statistical significance was found, the elasticity of VMT with respect to population and/or jobs density was modest (R. Ewing & Cervero, 2010; Kuzmyak, 2009; Zegras & Srinivasan, 2007; Zhou & Kockelman, 2008). Certain studies have reported a significant connection between density and VMT. For example, (Chatman, 2003) reported that urban density in the workplace area affects VMT.

In our interpretation, the mixed results about the impact of density on VMT are in part due to methodological choice made by the analysts. As R. Ewing and Cervero (2010) pointed out, density is an *intermediate* variable and is often correlated with or represented by other variables that have a more direct impact on VMT. For example, accessibility to destinations is found to have a strong connection with VMT. Density and accessibility to destinations are often found together, but density does not necessarily imply accessibility.

Urban design metrics such as the connectivity of the streets network and intersection density (for example, reducing the use of cul-de-sacs) are found to have a significant effect on VMT, because greater connectivity offers shorter routes to destinations (R. Ewing & Cervero, 2010; Gómez-Ibáñez et al., 2009). A factor that strongly influences VMT is the location of the residential development in the context of the region—this applies to any development, regardless of its density. As noted by R. Ewing and Cervero (2010), "almost any development in a central location is likely to generate less automobile travel than the best-designed, compact, mixed-use development in a remote location." This conclusion lends support to infill and centrally located developments as a powerful tool to reducing VMT (R. Ewing & Cervero, 2010).

The effect on VMT of urban design and land use planning elements, taken individually, may be relatively modest, though their cumulative effect can be more substantial. Table 0-2 shows a sample of individual measures that could be adopted in a Sustainable Community Strategy and the ranges of their potential impacts on VMT, as estimated by studies.

Table 0-2 Effects on VMT of Potential Planning/Policy Measures (Ewing & Cervero, 2010)

Measure	Type of VMT affected	Change in VMT per 10% increase in measure
Population, household or parcel density	Per household or person	-0.4% to -1.2%
Job density	Non-work or commercial	-1.9% to -3.4%
Land use mix	Per household	-0.2% to -2.7%
Intersection density	Per household	-0.8% to -2.9%
Distance to downtown or to CBD	Per household	-1.8% to -2.7%
Job accessibility by auto	Per household	-0.6% to -3.1%

Estimates of the cumulative effects vary. One study suggests that a 10% change in city shape (more circular city contour), road density, rail supply and jobs-housing balance could induce a change in VMT of no more than 0.7% each (Bento, Cropper, Mobarak, & Vinha, 2005; Kramer, 2013). If pricing (e.g. VMT fees and paid parking) is included as a strategy, the impact could be more significant. Rodier (2009), for example, found that a combination of land use, improved transit and pricing could achieve a 14.5% reduction in VMT in 10 years and a 24.1% reduction in 40 years (median values).

Several studies have shown that at least part of the difference in VMT between alternative and auto-oriented neighborhoods stems from differences in lifestyle (including travel) preferences of the households who choose to locate in each type of neighborhood. This effect is often referred to as "self-selection." Part of the difference in VMT is nevertheless attributable to the effect of the built environment on travel behavior (X. J. Cao, Mokhtarian, & Handy, 2009).

Other Sources of Emissions Reductions

In addition to their potential for reducing VMT, land use and urban design strategies can also reduce GHG emissions in other ways. Compact and infill development can increase the energy efficiency of non-transportation infrastructure, thus reducing their carbon impact. Apartment buildings typically use less energy per resident than single-family homes (Bedsworth et al., 2011).

Changes in land use from developments also impact GHG emissions directly (Houghton, 2003). Conversion of natural ecosystems or agricultural land to urban lands can release large amounts of carbon into the atmosphere through the removal of biomass and excavation and may substantially alter the carbon flux of the associated land area. To the extent that land uses displaced by urban developments are relocated, they will likely generate additional carbon emissions elsewhere; an effect known as indirect land use change, of great concern for example in biofuels policy. The climate impact from land use change has not, to our knowledge, been adequately recognized by development policies to date, and may have very significant effects on the carbon accounting of urban and suburban developments.

Additionally, urban land uses can also modify regional climate through the heat island effect, raising local temperatures by reducing evaporative cooling and storing heat in pavement and building materials (Foley et al., 2005). Infill and denser development, adequately planned, can reduce these impacts by reducing overall conversion of lands to urban uses.

Cost Effectiveness

Literature with estimates of the cost effectiveness of implementing SCSs using clear metrics such as dollars per ton of carbon emissions reductions is not typically analyzed or reported, to the extent of our investigation. In general, it is also difficult to assess the cost effectiveness of RTP/SCSs based on information provided in the plans and other reports that we examined. Because SCS are integrated into RTP, the best way to measure the benefits of a SCS is relative to a no-SCS RTP baseline (i.e. the RTP that would have been developed had SB 375 not been passed). Plans provide data on costs and savings projected from the implementation of certain elements of their plans, but the comprehensive data on the entire set of costs and savings needed to obtain good measures of cost effectiveness is generally not available in the literature.

A more recent example is the SCAG SCS. SCAG adopted a number of indicators to measure the success of its plan. These include land consumption, percent of work trips less than three miles, person delay per capita, among others. It also adopts a benefit/cost ratio indicator of cost effectiveness, for which it sets a "greater than 1.0" target. SCAG defines benefits as the "monetized user and societal benefits" and costs as the "agency transportation costs." Cost effectiveness defined in this way may not represent the entire picture if the benefits include those resulting from all projects (implemented by public and private sectors) and the costs include only costs to the public sector.

SCAG anticipates that the implementation of its RTP/SCS will result in 9% and 16% reductions in per-capita GHG emissions in the region, by the years 2020 and 2035, respectively. Total passenger vehicle GHG emissions in a weekday were 204.65 thousand tons. By 2035, these emissions are projected to rise to 222.88 and 249.15 thousand tons, for the cases with and without the SCS plan (California Air Resources Board, 2012).[9] This daily reduction of 26.27 thousand tons would give a reduction in annual emissions for the year 2035 of 9.457 million tons of CO_2.

There are estimates of specific costs and savings that may result from the implementation of SCSs. For instance, SCAG estimates that the aggregate cost to local governments of buildup, operation and maintenance of road infrastructure, if they chose to follow the land use patterns proposed in the 2012 plan, could go down to $27.2 billion, compared to the $33.2 billion that would result if development trends in the last decades were extrapolated to 2035. This represents 18% ($6 billion) in potential savings for the aggregate of all local jurisdictions in the SCAG region, over the 2012-2035 period. Similarly, SCAG estimates that, in local jurisdictions that choose to follow their RTP/SCS, households could save 15% in transportation and residential energy and water costs (on average, $16,000 in annual costs, down from the projected $19,000). For a comprehensive estimation of cost effectiveness, however, *all* direct costs and benefits of SCS implementation should be accounted for, including those to regional governments, local governments, households, and the private sector. We have not found studies that provide such estimates.

Most of the cost of the implementation of SCS would be covered from local funds. According to SACOG, about 95% of local road maintenance, at least 75% of transit operations, and 65%-90% of major capital investments on the road networks are covered with local funding. Local funding sources include sales taxes, fuel taxes, developer fees and contributions, general funds and transit fares. For example, the SCAG RTP/SCS states "As a means of backfilling declining federal and state sources,

[9] The SCAG RTP/SCS does not provide data on absolute reductions in carbon emissions resulting from the implementation of the plan.

the SCAG region continues to rely heavily on local sales tax measures for the timely delivery of transportation projects. Most counties in the region voted to support local sales taxes to fund transportation projects" (Southern California Association of Governments, 2012). Indeed, local option sales tax measures and the revenues from the Local Transportation Fund from the Transportation Development Act, combined add to over $148 million of the $226 million in projected local sources to support implementation of the RTP/SCS. Development impact fees would account for just $9.5 million. Under such funding structure, local jurisdictions have strong financial incentives to reduce road expenditures.

As an example, the City of Palo Alto's 2014 budget includes $60.8 million in capital expenditures. The funding sources that cover these expenditures are shown in Table 0-3.[10] Of these, expenditures from the Capital Project Fund (General Fund) amount to $34 million (or 56%). Streets and sidewalks accounts for 27% of these ($9.2 million), only second to parks and open space. Traffic and transportation is the fourth largest expense, at 14% ($4.76 million).

Table 0-3 Funding sources for the City of Palo Alto

Funding Source	Percentage	Amount (millions)
Infrastructure reserve	31%	$18.85
Utility rate charges & fees	26%	$15.81
Federal/state & local agencies	13%	$7.90
Debt financing	8%	$4.86
Storm drainage fee	6%	$3.65
Vehicle fund balance	5%	$3.04
Transfer from general fund	3%	$1.82
Gas tax	3%	$1.82

Some of these sources of revenue are consistent with the implementation of SCS, while others can conflict, depending on how they are collected. For example, development fees and taxes can create incentives to encourage single-family and discourage multi-family development. Table 0-4 shows a hypothetical but realistic numerical example developed by SACOG of development fees for a 2,000-square-foot single-family units development and a 45-unit multi-family development.

Table 0-4. Example of development fees for single- and multi-family developments in the SACOG region

Development Costs	New Single-Family	New Multi-Family
Total fees	$15,700/unit	$9,000/unit
Cost to develop	$95,700/unit	$110,000/unit

[10] We only show sources that account for three percent or more of the total.

Fee as percentage of development cost	16%	8%
Total cost (development plus fees)	$111,400/unit	$119,000/unit

In this example, fees are a lower fraction of the development cost for multi-family units, but still the *combined* per-unit cost of development and fees is higher for multi-family units.

Table 0-5 shows the types of fees that apply to any given development, those over which the city has authority, and representative percentages of the total development fees.

Table 0-5 Development fees' decomposition and jurisdiction

Fee Type	Jurisdiction	Typical Percentage
Planning	City government	7%
Building	City government	10%
Traffic impacts	City government	3%
Parks	City government	7%
Community facilities	City government	14%
School impact	School district	23%
Water and sewage	Municipal utility district	32%
Environmental impact		4%

Some of these fees are the same, and others would differ depending on whether they are applied to single-family vs. multi-unit developments, and in-fill vs. greenfield developments. Several elements in Table 0-5 are worth noticing:

1. Local governments have control over less than half of the development fees;
2. SCS implementation will presumably require more comprehensive planning, including modeling. Planning fees based only on property cost of development do not recognize this;
3. Traffic impact fees are assessed based on the type of development. To implement SCS, it would be logical not to focus on local traffic impacts but rather to take a more regional perspective on the traffic implications of each development type.

The costs associated with the planning of these strategies will also fall primarily on the regional and local governments. Legislative analysis of SB 375 estimated the ongoing costs to the state for program administration at less than $1 million annually. The same analysis expected increases in the cost to MPOs and local jurisdictions due to increased planning complexity, though it did not specify the extent of such increases (Stivers, 2008).

Infill and compact developments would also generate savings from avoided road infrastructure construction and maintenance. Studies have also found that coordinated land use and transportation planning can increase economic productivity and reduce housing, transportation, and labor costs. For example, a study finds that substitution of multi-family housing for single-family housing can increase household funds available for other purposes (Rodier, Martin, Spiller, Abraham, & Hunt, 2012). Municipal infrastructure (such as water and sewage systems) in infill or compact developments may be more complex and have higher upfront costs compared to greenfield developments, but the long term costs on a per-capita basis are lower (Urban Land Institute, 2010).

MPOs also expect that transit ridership and transit system efficiencies will increase if and as more transit-oriented developments are implemented. Under such conditions, per-rider revenues from transit fares would increase, which would help lower public subsidies needed to maintain service and support financially the implementation of SCS, thus creating a virtuous circle.

Intuitively, one could expect that the cost of infill development would tend to be lower than that of suburban developments. We found, however, that the literature on this question is not conclusive. A number of studies have found, through modeling or the analysis of hypothetical neighborhood designs, that this may be indeed the case (E.g. Rodier et al. (2012)). Conclusions from modeling studies were, however, criticized on the grounds that they are generally based on hypotheticals and tend not to account for important factors, such as the real costs of expanding infrastructure in areas of higher density (McConnell & Wiley, 2010). Ladd (1992) finds that infrastructure costs in new developments increase with density, while Farris (2001) additionally notes that even though infrastructure may already exist in infill locations, it frequently needs to be updated, adding to cost. Snyder and Bird (1998) cited a few studies noting that the cost of services for sprawl is higher, but also noted that pricing may not reflect this. Another cost that developers may face in urban settings is that of assembling the required number of parcels, which usually have different owners. The degree of willingness of owners to sell the targeted parcels will influence the cost of land. Further, dealing with a set of different owners carries challenges of its own, such as increased legal and financial risks, which in turn enter into the economic calculations of developers as well as lenders (Farris, 2001)

Analyses have suggested that urban growth that leaves land spaces undeveloped, even if it results in some “leapfrog development,” may be economically efficient over longer periods of time (Peiser, 1989). The value of these undeveloped spaces will grow over time for several reasons, including a) the access to infrastructure and amenities built around them, b) access to community benefits, and c) increasing costs of transportation with the increase in the metropolitan area. The higher land value per unit of area resulting from these factors would eventually induce higher-density developments, as developers trade space for capital (Mills, 2002; Nassar, 2007).

It seems clear that market imperfections have resulted in an over-supply of suburban housing. If consumers were paying the real cost of (and associated with) suburban developments, the demand for such developments would drop. Examples of the market distortions include:

- Incomplete internalization of local service costs. Even when delivering services to suburban developments tends to have higher costs, these are rarely fully internalized by taxes, utility rates, etc.;
- Excessive space requirements. Zoning codes and development regulations have minimum requirements on space dedicated to parking and roadways, which discourages higher-density developments and often-oversupplies parking;
- Pricing of roadway right of way. Land dedicated to roadways and parking is not taxed comparably to competing uses, thus incenting a lax approach to land use for these purposes;
- Suburb-oriented planning. Some planning practices favor lower-density, automobile-oriented developments; and
- The subsidization of transportation fuel. To the extent that the social costs of fuels consumption, such as road infrastructure use and pollutant emissions are not properly internalized, public policy is favoring auto-oriented housing developments.

Markets are not static, however, and if the costs listed above were internalized the market may not only shift toward development and travel behavior more consistent with the goals of SB375 but also react by increasing prices for alternative housing developments. This would happen partially because, as demand for developments consistent with SB375 increase, developers will see an opportunity for increased profits. Many studies and reports point out that smart growth development enables residents to save costs (Litman, 2014) ; (Dodson and Pipe, 2006). Some of the same studies point out that these savings would improve prosperity while they would also contribute to rising housing prices. For example: "Because these are true savings to home occupants, translate into higher property values, reduced vulnerability to economic downturns (…)" (Litman, 2014). These and other benefits, including accessibility, will tend to translate to higher prices. A study of 15 cities nationwide found that increased walkability is correlated with higher housing value, all else equal (Cortright, 2009). Similarly, a study of residential proximity to light rail showed housing values increasing with proximity to light rail stations up to one-tenth mile from the station (Rewers, 2009). Comparable results have been observed in several other studies (Bartholomew & Ewing, 2011).

While economic analysis offers many insights into the relative costs of urban vs. exurban developments, housing development is more often than not a *political economy* question. Regulations as well as local residents often influence the viability of projects. Urban development generally requires permits and public participation, for example in the form of hearings, which adds to development costs and uncertainty. Farris (2001) summarized the difficulties of infill developments as follows: "the practical barriers to urban infill development [include] land assembly and infrastructure costs, unwillingness to condemn, municipal social goal and regulatory policies, difficulty of finding developers, complexities of public-private partnerships, excessive risks, resistance from local residents, and stakeholder conflicts and political constraints." (p.1).

And then there is the question of road financing. The instituted form of finance for the construction and maintenance of roads is the collection of user taxes on fuel. This source of revenue has, however, not kept pace with inflation and the growth in population and VMT. This is critical problem for the state and national infrastructure and road-intensive developments add financial pressure to it. A study by the American Association of State Highway and Transportation Officials (AASHTO, 2009) reports that California has the roughest roads in the nation, and that 50% of pavements are rated poor in seven major cities. This poor state of our road system costs drivers $590 annually as added operation costs. For example, the percentage of roads rated fair or poor was 23% in San Jose, 20% for Sacramento, 14% in San Francisco-Oakland and San Diego, and only 10% in Los Angeles. While the road financing system waits to be fixed, mitigating expenditures on suburban road construction and maintenance would provide savings to users and local communities, and enable redirecting funds from roads to other community needs.

Technological and Behavioral Feasibility

The successful implementation of SB 375 depends on complex and interdependent factors, including institutional processes, consumer and investor choices, as well as technological and infrastructure factors. Institutional and regulatory factors, which are often intertwined with infrastructure and behavioral factors, are discussed predominantly in the next section (Administration).

From an infrastructure perspective, the long timeframes associated with large changes in the built environment mean that the macro-impacts of land use decisions on cumulative GHG emissions will occur over several decades. An estimated two-thirds of the buildings that will exist in 2050 would have been built after 2008 (Reid Ewing, Bartholomew, Winkelman, Walters, & Chen, 2008; A. C. Nelson, 2006). Thus, to achieve meaningful impacts on carbon emissions during the period contemplated by AB 32, land use strategies need to be aggressive and start with no delay.

From a market-behavior perspective, implementing SCSs will not be free of challenges. As planners like to say, "if there's one thing people hate more than sprawl, it's density" (Flint, 2006). Smart growth and New Urbanism focus on creating conditions for market acceptance of denser developments[11] (a minimum of

[11] The minimum density sought in New Urbanism developments is six units per acre, which highlights that not always does denser mean *dense*. In fact, what constitutes *dense* development is not clearly defined.

six units per acre), with mixed land uses conducive to displacing personal-vehicle mobility.

Beyond these strategies, the opportunities for developers and local jurisdictions to populate SCSs will depend to large extent on homebuyers' demand for alternative developments. More research will help to better assess the magnitude of this demand, as the evidence to date is relatively mixed. Some studies suggest that a substantial portion of residents experience a mismatch between their desired neighborhood type and the type of neighborhood where they actually live (Schwanen & Mokhtarian, 2004), and the desire for more walkable communities is growing and largely unmet (Handy, Sallis, Weber, Maibach, & Hollander, 2008), while other studies fail to find evidence of significant mismatch between current and desired neighborhoods (e.g. X. Cao (2008)).

In a national poll, Belden, Russonello and Stewart (2011) found that 28% of people would prefer to live in suburban neighborhoods with mixed land use, while 12% would prefer to live in residential-only suburban neighborhoods. Nineteen percent indicated a preference for living in a city. The preference for mixed-use suburban neighborhoods is particularly interesting and relevant for the implementation of SCSs. It is reflective of people's fondness for living in places that are walkable and within a short distance to shops and other amenities, while retaining their fondness for the privacy of the suburban home. Two important questions follow: To what extent can land use plans simultaneously accommodate these amenities? And which one tends to be more important to people? The same study sheds light into the latter: Sixty-one percent of respondents indicated that they would choose a residence with a larger lot and needing to drive, over a residence with a smaller lot with the ability to walk to shops, schools and other amenities. Eighty percent of respondents expressed a preference for single-family detached homes, although commute time is a very important factor and many people are willing to trade residential space for shorter commutes.

Per SB 375, the decision to implement SCSs is ultimately left to local governments. It is however important to recognize, as Levine and Frank (2006) discuss, that sprawl is itself, to a large extent, the result of municipal regulations. Such regulations often come in the form of zoning that promotes or mandates land uses characteristic of suburban development. Regulatory failures include limits on housing density, excessive approval process within the urban boundary, requirements on parking capacity, mandating wide streets, and separating land uses. For example, Pendall (1999) found that regulations such as low-density zoning contributed to suburban-style developments and auto-oriented travel patterns. These concepts were effectively articulated by Downs (1999):"[T]he belief that sprawl is caused primarily by market failures, is based on the false assumption that there is a freely operating land use market in U.S. metropolitan areas. No metropolitan area has anything remotely approaching a free land use market because of local regulations adopted for parochial political, social and fiscal purposes".

Most cities and counties also have ordinances requiring a minimum number of parking spaces to be established based on a ratio of the square feet of development or number of residency units to accommodate periods of peak demand in all areas of a city. Minimum parking requirements hinder infill and compact development and foster auto-dependency. In infill areas where car ownership and use would not be as necessary as on the urban fringe, developers may have difficulty finding the space or the funding to implement required parking within their project. Willson (1995) found that parking requirements for developments lead to oversupply of parking space and impact urban form as well as travel patterns. To reduce this problem, in February 2011 AB 710 proposed elimination of minimum parking requirements higher than one space per thousand square feet of development. The bill, however, was opposed by cities because it "impede[d] local discretion" and ultimately it failed to pass (Lawler, 2011; Skinner, 2011).

In a survey of developer members of the Urban Land Institute, Levine and Inam (2004) found that developers believe that demand for alternative development is greater than the actual supply, but that municipal regulations are the number one obstacle to increase this supply. In a different study, using data from a survey of households in Northern California, (X. Cao, 2008) found no evidence of unmet demand for alternative developments. Residential choice is dominated by considerations such as dwelling price, neighborhood safety, and neighborhood quietness, while accessibility to alternative transportation systems and land use are much less important. Subjects of this study expressed that their preferences for accessibility factors (e.g. abundance of sidewalks, proximity to shopping areas, availability of good bicycle paths beyond the neighborhood, good public transit service, etc.) were exceedingly met by the characteristics of the residence and neighborhood that they had chosen. We believe that there is a need for more research to better understand the extent and characteristics of the demand for sustainable development in California and whether local regulations may prevent any existing demand from being met. Based on (X. Cao, 2008), it appears that homebuyers appreciate qualities such as safety and quietness, which can be correlated with low use of personal vehicles, precisely the key characteristic that SB 375 pursues. However, experience seems to show that reconciling these characteristics in the same neighborhood may be challenging.

Also worth considering is that, as the population ages, it is likely that the demand for single-family homes will decline as the baby-boom generation moves into smaller housing. Though smaller than the baby boomer generation, Generation Y has a greater propensity for urban living than their predecessors, which will also likely increase the demand for alternatives to single-family homes.[12] Overall, by 2035, a net reduction in the demand for conventional-lot, single-family homes and increased demand for multifamily, townhouse, and small-lot single-family homes is expected (Gómez-Ibáñez et al., 2009; A. Nelson, 2011). If materialized, this projected demand

[12] Generation Y: people born between 1979 and 1996 (A. Nelson, 2011)

will provide opportunities for builders if the deterrents discussed earlier are removed.

Administration

To meet their targets, each MPO identified existing land uses, identified suitable areas to house their expected population, identified a transportation network (infrastructure for motor vehicles, transit, cycling, and walking), forecasted development for the region, and created a transportation plan that would meet those targets (Steinberg, 2007). Sustainable Community Strategies used by MPOs typically include increased spending in transit and active transportation, emphasis on mixed-use and compact development, and promotion of infill development and preservation of open space and farmland ("The Blueprint Vision," 2013; Rose, Bernstein, & Cohen, 2011).

Taking SACOG for illustration, we show below a sample of the project that the region is considering toward implementation of their MTP/SCS:

- Placing emphasis on road maintenance and rehabilitation;
- Expanding “complete street” projects, that take a more holistic approach to street planning and construction, by not focusing only on flow capacity but also on facilities for pedestrians, bicycles, and transit, as well as considering elements related to safety, ADA accessibility, goods movement, etc.;
- Emphasis on creating networks of complete streets within and between communities;
- Increasing transit level of service, including higher frequencies and greater regional coverage.
    - Daily vehicle service hours will be increased by 98%, from 4,074 hours to 8,062 hours;
    - Decreasing service waiting time to 15 minutes or less for higher-density mixed-uses;
- Introducing new transit services, including bus rapid transit;
- Increasing the number of buses running on alternative fuels;
- Increasing level of service on the San Joaquin intercity rail line;
- Increasing transit security;
- Implementing carpool lanes (for example between Davis and West Sacramento);
- Street environment enhancements that foster street calming, better landscaping, sound walls, and other elements.

Local government authority over SCSs implementation

While SB 375 directed that MPOs develop Sustainable Community Strategies integrating land use and transportation planning, the MPOs do not have direct control over the implementation of the plans they develop. Land use decisions are made by local jurisdictions. MPOs may have some leverage for incenting local compliance with these strategies, but implementation by local jurisdictions is voluntary. Thus, it is ultimately cities and counties who will determine the extent to which SB 375 is successful. As a consequence, the extent to which modeled emissions reductions will correlate with *actual* emission reductions is uncertain. We discussed above the importance of the regional context on the effect that a given development could have on residents' VMT. However, the local control of the implementation of SCSs and the evaluation and approval or disapproval of developments often conflicts with the use of regional-level perspectives. Thus projects that could bring about benefits at the regional level might not be favored if their impacts are not in the interest of the respective local residents or local governments (E. Barbour & Deakin, 2012).

Local leaders may also reject adopting local land use plans that are consistent with the SCS for their jurisdictions in response to their local voters. One reason why opposition to these plans could arise is the suspicion that they may promote excessively dense housing developments and neighborhoods (Duffy, 2013). Residents have varied opinions regarding denser development. Though some residents desire denser infill development and welcome it as a new residential option, other residents are strongly attached to their current suburban neighborhoods, do not see them as environmental problems, and are generally unaccepting of more dense traditional development (Elisa Barbour & Teitz, 2006; Downs, 2005; Talen, 2001). Residents who live in areas with increasing density may feel the costs, perceived or real (such as increased traffic) on quality of life but not the larger benefits (such as new jobs, increased income, and GHG reduction) to the region and climate (Cinyabuguma & McConnell, 2013). For both residents and businesses, fundamental human resistance to change also makes implementation of plans differing from past practice difficult (Downs, 2005). Thus, political support may flow to leaders who resist implementing SCSs.

California Environmental Quality Act (CEQA) Considerations

CEQA reinforces local jurisdictions' authority to make the final decision to approve a project, which results in relatively uncertain outcomes (Elisa Barbour & Teitz, 2005). Even when a local community seeks to develop in accordance with its regional SCS, conflicting state requirements may hinder it from doing so. In particular, CEQA directly and indirectly leads to a preference for greenfield development. CEQA requires proposed projects, including proposed developments to identify and mitigate environmental impacts associated with the project. Though SB 375 provided streamlined CEQA review for some projects consistent with an SCS, it has been argued (Rose, 2011) that the criteria for these projects may be too strict to have any significant effect. We have not found hard evidence on the effective value of the proposed streamlined review process on developers' decisions to date.

Another way in which CEQA may unintentionally deter SCS implementation is with its use of a "fair argument" standard for determining the impact of a development.

This standard may be open to interpretation and has created uncertainty and inconsistency about CEQA's requirements for specific projects (Elisa Barbour & Teitz, 2005). To the extent that legal challenges may become a concern, developers may be less likely to pursue infill development, with its inherently larger number of affected parties, than greenfield development (Lichty, 2012; 2012).

Currently, the definition of *significant impact* in the CEQA process includes a reduction in automobile level of service (LOS), namely a substantial increase in traffic congestion.[13] Mitigation of such impacts is typically addressed with the expansion of roadway capacity, which may be detrimental to non-automobile transportation modes. Furthermore roadway expansion may not be feasible in all cases, particularly in the built-out neighborhoods in which infill projects are typically constructed (Wise, 2013). Because of the focus on LOS, development in outlying or greenfield areas has often been favored over infill (Jaffe, 2013). SB 743, passed in late 2013, may help remedy this problem. This bill directs the California Office of Planning and Research to create new metrics for areas near high-quality transit that promote GHG emissions reduction, non-automotive transportation modes, and land use diversity by July 2014 (Steinberg, 2013). One possible replacement metric is minimization of automotive trips generated, which could substantially change the outcomes of CEQA impact determinations (Jaffe, 2013). New methods are being developed to more accurately estimate the lower volume of vehicle trips that infill projects will generate (Schneider, Shafizadeh, Sperry, & Handy, 2013).

Distributional Effects

As deterrents are removed and SCSs are implemented, care needs to be taken to ensure changes are made equitably, without disproportionately impacting disadvantaged communities. In addition to aligning land use planning and transportation planning, SB 375 also links both of these regimes to housing by requiring local jurisdictions to create general plan housing elements consistent with their Regional Housing Needs Allocation and enacting zoning consistent with that plan (Eaken, Horner, & Ohland, 2012). Historically, MPOs have tended to over-represent suburban constituencies and underserve the needs of low-income populations (Karner, 2013). SCSs can help remedy these deficiencies by supporting objectives such as maintaining and increasing bus service and prevention of displacement (Eaken et al., 2012). Emphasis on infill and non-automotive transportation may help achieve social equity objectives. Mixing land uses and providing additional transportation options can increase accessibility and mobility for populations underserved by current options. Additionally, MPOs and other jurisdictions need to provide all communities the opportunity to participate effectively in planning processes as SCSs are developed and implemented (Karner, 2013).

[13] Significance is a relative subjective term and the lead agency can use it judgment to assess each case based, to the extent possible, on scientific or evidence-based information.

SB 375 is explicitly concerned with SCSs to be accessible to Californians regardless of their income segment. It specifies: "identify areas within the region sufficient to house all the population of the region, including all economic segments of the population". The development of denser housing is almost certainly cheaper per unit than less dense housing built in the same location, but alternative housing, particularly if limited in supply, can become more expensive as price captures the value of centrality, accessibility, and other benefits, as discussed above. MPOs and cities will have to find ways to implement neighborhoods that have the amenities needed to invite overall displacement of the automobile while remaining affordable.

Scalability and Transferability

The notion of integrating land use with transportation planning is applicable universally. In fact, about 20 states have adopted policies or programs to support smart-growth and infill development that attempt to capture some of their potential benefits to communities. Probably the most renown of these programs is Oregon's Urban Growth Boundary (UGB), initiated in 1977 to control sprawl and promote transit-friendly higher densities.

Discussion

There is sufficient evidence that a number of land use and urban design strategies can help reduce driving. Reductions in VMT from specific strategies, however, are not easily quantifiable and cannot in turn be translated easily into quantifiable reductions in GHG emissions (emissions depend not only on the number of miles driven but also on the efficiency of those miles).

The carbon reduction goals for MPOs are set and shown in Table 0-1. We believe however that if SB 375 is to achieve its intended goals, several issues that may limit its effect will need attention. These include:

- The complexity of the various processes involved. The implementation of SCS is affected by myriad local and political factors the outcomes of which are relatively uncertain. The impact of these outcomes in turn is difficult to predict with much confidence, to the extent that the relation between specific SCS strategies and the associated carbon emissions reductions is subject to uncertainties.
- Low local prioritization of development consistent with SCSs. Local jurisdictions control implementation of SCSs through local land use policies and project decisions and approval; their interest in generating revenues (e.g. through sales taxes) and the potential local resistance to changing the status quo may reduce their likelihood of implementing land use changes consistent with these SCSs;
- Incongruence of existing local regulations. Certain current regulations requiring separation of land uses and minimum numbers of parking spaces

are not consistent with encouraging higher density, mixed-use developments that are consistent with SCSs;

- Permitting process. More cumbersome requirements in the development permitting process increase developer costs of infill development compared to greenfield development and create disincentives for the former;
- CEQA's emphasis on level of service. The focus of the law on and definition of LOS impacts favors development in greenfield areas and may lead to expansion in roadway capacity;
- Limited enforceability. While SB 375 does include incentives for developers, it does not include strict requirements on local governments to implement SCSs.

Several strategies may be adopted to address these concerns and improve the implementation of SCSs and their impact toward SB 375 goals. One such strategy is to address the underlying public perception and understanding of the benefits of SCSs. For example, it should be clearly explained that SB 375 does not *mandate* density, or outlaw single-family houses. The broader potential benefits of good land use policies should also be communicated effectively. It has been shown that many citizens do not understand the link between land use and environmental harm (Gocmen, 2009; Talen, 2001). However, these same citizens may be aware of the direct impacts (such as increased travel time) of sprawl on their own quality of life (Talen, 2001). Connecting the personal benefits for daily life and the potential for other benefits from SCSs to larger environmental issues may help to increase support for SCSs and VMT reduction (Long, 2010).

To address the asymmetric costs and benefits to existing residents caused by construction at infill sites, compensation or carrots could be offered to those residents. Subsidies or decreased taxes on existing residents may induce them to accept new development. However, impact fees from those new developments might be too low to fully cover those incentives (Cinyabuguma & McConnell, 2013). Another option might be to internalize the full costs (economic and societal) that suburban development imposes on the system (which affect negatively the competitiveness of infill and alternative developments). This idea has not been examined in depth in the literature, to our knowledge.

Direct funding for local jurisdictions to update their general plans and zoning to align with SCSs could also increase adherence to regional plans. Such funding may be particularly beneficial for the nearly half of local jurisdictions which have general plan land use elements that are out of date (Rose, 2011), and may also be most effective in relatively less well-off inland areas which may be less likely to make plan and zoning changes on their own. The State of California Strategic Growth Council is awarding Proposition 84 (The Safe Drinking Water, Water Quality and Supply, Flood Control, River and Coastal Protection Bond Act of 2006) funding to local governments to develop and implement plans leading to reductions in GHG emissions (California Strategic Growth Council, 2013). Additional funding could be provided from a revival of redevelopment programs, cap and trade revenues, or direction of flexible transportation funds to jurisdictions implementing SCS (Eaken et al., 2012; Sciara & Handy, 2013). In fact, the 2014-15 state budget proposes $100M from cap and trade funds for the Strategic Growth Council to support implementation of SCSs (Brown, 2014). Similar programs implemented in California prior to the adoption of SB 375 have been successful in achieving regional goals (Altmaier et al., 2009; Sciara & Handy, 2013). Two elements of any such incentive mechanisms would be critical: a) ensuring the fair distribution of incentives across jurisdictions, and b) distributing incentives to cities and counties working to meet SCS plans and based on clear metrics related to the carbon emissions reductions measured or expected from these efforts (Altmaier et al., 2009; Sciara & Handy, 2013).

These actions would also provide financial and political support to local officials to pursue SCS implementation. Additional interventions to reduce local prioritization of sales tax revenue generators such as auto dealerships and big box stores would also be helpful. One possible method would be to share sales taxes beyond the jurisdiction in which they are collected, increasing the alignment between regional costs and benefits. This allocation could be done regionally, as implemented in the Minneapolis area in 1974, or on a statewide basis (Chapman, 1998; Reschovsky, 1980; Reschovsky & Knaff, 1977; Schwartz, 1997).

Even if all obstacles are removed, the rate of transformation of the housing stock will take time. While it seems clear that there is a demand for many of the attributes of alternative developments (e.g. walkability and access to amenities within walking distance), the extent of this demand and the degree to which homebuyers may be willing to switch from suburban, car-oriented housing to compact, transit-oriented developments still needs to be better understood. To the extent that the social costs of living in suburban neighborhoods are subsidized, the observed demand for alternative developments will likely remain suppressed and not reflective of real market conditions.

More research is needed to help clarify the magnitude and characteristics of the demand for more compact, resource-efficient neighborhoods consistent with SCSs, to better understand the impacts on carbon emissions that may be expected from SCSs, as well as ways to encourage and support their implementation. Longitudinal studies are better suited to determine the impact of changes in the built environment on changes in VMT and GHG emissions. Finally, there is a need for studies on the effectiveness of changes in local land use policy and the implementation of other strategies in creating more compact, mixed-use communities are needed (Boarnet, 2010; Salon, Boarnet, Handy, Spears, & Tal, 2012).

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The Low Carbon Fuel Standard

Julie Witcover, Jeff Kessler, Anthony Eggert, and Sonia Yeh

Key Findings

- The Low Carbon Fuel Standard (LCFS) is a technology-neutral performance standard that stimulates innovation by providing financial incentives to reduce GHG emissions along the entire supply chain for transportation fuels
- The LCFS rates each fuel's carbon intensity using lifecycle analysis emissions estimates, including indirect land use change emissions. Carbon intensity ratings should be updated according to a known schedule, to reflect scientific advances.
- Fuels that have the most potential for contributing to meeting the LCFS include low-carbon biofuels, renewable natural gas, electricity and hydrogen
- The LCFS has seen a large number of new low-carbon biofuel companies registered under the program, and a reduction in carbon intensity ratings of conventional ethanol; much greater emission reductions will be needed to achieve the 10% reduction required for 2020
- The LCFS is revenue neutral: cost added to high carbon fuels under the program is transferred directly into incentives for low carbon fuels. The LCFS can result in higher transport energy costs, if the low-carbon fuels used are more expensive than conventional fuels. Some low-carbon fuels, like biofuels, are currently more expensive than gasoline; others, like electricity and natural gas, are lower than gasoline and diesel on a per energy unit basis, but may require additional vehicles or infrastructure, with their own costs, before they can be used in the transport pool.
- The LCFS credit has fluctuated between $15 and $80 per tonne CO_2e and remained at $20-$30 from mid-2014 through early 2015. CARB is expected to adopt a price ceiling of $200 per tonne on credit transactions, and allow deficits to roll over (with interest) for up to 5 years in a systemwide credit shortage situations. LCFS credit values are not equivalent to carbon prices within the state's Cap and Trade program. An LCFS credit price of $25 in 2015, when only 1% reduction in carbon intensity is required, translates to a cost increase of about $0.003 per gallon of unblended gasoline, while a price of $200 in 2020 when a 10% reduction in carbon intensity is required translates to $0.24 per gallon.
- The cost of compliance in the future depends on technological progress, advanced fuel investment, and market responses

- The California Air Resources Board is expected to adopt the following amendments to the LCFS in mid-2015: a cap on credit prices of $200 per tonne plus deficit rollover for up to 5 years in situations of systemwide credit shortage; streamlined certification of fuels; modest reduction in carbon intensity ratings of crop-based biofuels (due to lowered estimates for indirect land use change emissions), and back-loading the compliance schedule to make requirements more modest until the few years leading up to the 10% reduction required for 2020.
- Other jurisdictions are implementing or considering implementation of an LCFS. Adoption of similar programs by other states could pioneer a mechanism for coordination and for scaling the California LCFS.
- The LCFS and similar programs promoting biofuels and other alternative fuels can have effects (both positive and negative) on food prices and the environment, with impacts to water availability or biodiversity. The policy should include mechanisms to monitor and mitigate unintended consequences. Evaluating indirect land use change, as in the California LCFS, is one such mechanism.

Background

California's Low Carbon Fuel Standard (LCFS) was initiated by Executive Order S-1-07 in early 2007 and adopted by the California Air Resources Board (CARB) as an AB 32 early action regulation in April 2009. The LCFS aims to reduce greenhouse gas (GHG) emissions in the transportation sector by reducing the average fuel carbon intensity (AFCI) of transportation fuels sold in the state. Fuel carbon intensity is defined as the amount of GHG released through a fuel's lifecycle including extraction, conversion, transport and delivery, and consumption – the entire supply chain – including emissions from indirect land use change.[14] It is expressed as grams of carbon dioxide equivalent (CO_2e) per unit of energy delivered, typically in megajoules (CO_2e/MJ).

The standard is tightened over time to encourage and allow time for cleaner fuel technologies to become more cost effective through innovation, economies of scale, and experience (Yeh & Sperling, 2010). The current policy targets a 10% AFCI reduction by 2020 from 2010 levels.

Fuel policies like the California LCFS have been proposed in other jurisdictions in the United States as well as abroad. The European Union developed, in parallel, a policy similar to the LCFS known as the Fuel Quality Directive (FQD) shortly after California instituted its LCFS (Sperling & Yeh, 2009). British Columbia has also followed suit with a similar policy, the Renewable and Low-carbon Fuel Requirement Regulation (LCFRR). The Northeast and Mid-Atlantic states have

[14] Indirect land use change can occur when fuel feedstocks displace existing land use, triggering market responses that can result in land conversion elsewhere, in compensation.

conducted LCFS studies and discussions, while Oregon and Washington have moved more recently toward implementing similar fuel intensity standards.[15]

In California's LCFS, the baseline AFCI is calculated using the state's fuel mix in 2010 for two different fuel pools: gasoline and diesel. For the baseline year (2010), the AFCI is calculated to reflect the amount, for the gasoline pool, of reformulated gasoline blend-stock (CARBOB) and ethanol used in the state (93.48% CARBOB and 6.52% ethanol by volume) (California Air Resources Board, 2009); and for the diesel pool, of 100% Ultra Low Sulfur Diesel (ULSD). **Error! Reference source not found.** shows the current fuel carbon intensity (CI) ratings for a small selection of fossil and alternative fuel pathways.

To account for differences in vehicle efficiency across powertrain technologies, CARB uses energy economy ratios (EER) that scale a fuel's emission pathway to reflect the efficiency of the vehicle technology. For example, the EER for electricity in the program is 3.4, reflecting CARB's assessment that battery vehicles using electric motors are over three times more energy efficient than similarly-sized conventional internal combustion engine vehicles burning liquid fuel. This EER adjustment reduces the effective CI rating of electricity from 124 gCO_2e/MJ to 36.5 gCO_2e/MJ.

California's LCFS tracks the GHG performance of fuels through a pathway approval process. Currently, a default life-cycle carbon intensity rating is established for each fuel, and regulated parties are allowed to submit their own carbon intensity ratings for approval (California Air Resources Board, 2011). As of spring 2014, the available fuel pathways in the program numbered over 250, about 50 generated by CARB and the rest submitted by regulated parties. CARB is proposing a streamlined certification process (for adoption in 2015) to reduce the administrative burden due to submitted pathways, without jettisoning an incentive for small, incremental improvements in carbon intensity. It aims to speed carbon intensity assessment for familiar technologies and allow staff to concentrate on evaluating newer, less familiar technologies.

To comply with the standard, the average carbon intensity for all fuels sold for use in California must be at or below the AFCI standard in a given year. If a fuel provider's fuel carbon intensity rating exceeds the regulated requirement, the provider generates deficits. Analogously, if a fuel provider's fuel carbon intensity rating is under the standard, the provider generates credits.[16] Parties with net deficits can maintain compliance with the LCFS by selling credit-generating fuel directly into the transport market, or by purchasing LCFS credits generated by

[15] Oregon's Clean Fuels Program was in a reporting-only phase in 2014, and has a baseline year in 2015. The program requires legislative action to continue with planned CI targets in 2016. Washington conducted technical and economic analysis on a potential Clean Fuel Standard in 2014, and began a stakeholder process to draft regulatory language in 2015.

[16] Credits and deficits are defined by CARB such that each credit (deficit) represents one metric ton of CO_2e reduction below (above) the annual AFCI standard.

others. Providers of fuels already deemed to meet the 2020 carbon intensity standard can 'opt-in' to the market, become regulated parties, and generate credits that they can then sell to generate revenue. Opt-in fuels include fossil and renewable natural gas, electricity, and hydrogen. These, plus low-carbon biofuels, are among the fuels with the most potential to contribute to LCFS compliance, especially as targets grow more stringent. Credits can also be banked for future use. This increases firms' flexibility in meeting the standard as it grows more stringent over time. The market-based trading mechanism among firms allows the program's targets to be met by industry at lowest cost. By providing additional revenue via LCFS credits, the policy creates new potential revenue streams for low-carbon fuel providers with revenue proportional to the volume of fuel sales and reductions in rated carbon intensity.

Table 0-1: Carbon Intensity values for selected fuels pathways under the California LCFS. Source: California Air Resources Board (2012)

Fuel	Pathway Description	Fuel Carbon Intensity (gCO_2e/MJ)		
		Direct Emissions	Land Use or other indirect effect	Total (including EER)
CARBOB	CARBOB - based on the average crude oil supplied to California refineries and average California refinery efficiencies	99.18	0	99.18
Ethanol from Corn	California average; 80% Midwest Average; 20% California; Dry Mill; Wet DGS; NG	65.66	30	95.66
Ethanol from Sugarcane	Brazilian sugarcane using average production processes	27.4	46	73.4
Electricity	California average electricity mix	124.1	0	36.5
Hydrogen	Compressed H2 from on-site reforming of NG	98.3	0	39.32
Diesel	ULSD - based on the average crude oil supplied to California refineries and average California refinery efficiencies	98.03	0	98.03
Biodiesel	Conversion of waste oils (Used Cooking Oil) to biodiesel (fatty acid methyl esters - FAME) where "cooking" is required	15.84	0	15.84
Biodiesel	Conversion of Midwest soybeans to biodiesel (fatty acid methyl esters -FAME)	21.25	62	83.25

* "Land use or other indirect effect" emissions refer to emissions associated with macroeconomic, or market-mediated, effects from the use of a given fuel. EER refers to the Energy Efficiency Ratio.

Compliance Options and Strategies

Regulated parties decide how to comply with the standard, based on economic and strategic considerations. Thus far, regulated parties have met the modest AFCI reductions requirements[17] primarily using existing production technologies with lower carbon inputs and efficiency-boosting process improvements. As AFCI reduction requirements become more stringent, compliance will likely require increased use of less conventional low-carbon fuels, such as electricity and hydrogen from low-carbon sources, and liquid or gaseous biofuels from biomass feedstocks that don't use arable land.

According to California data, by the end of 2013 regulated parties in California's LCFS still relied primarily on ethanol (which generated 64% of total credits) with decreasing (improving) carbon intensity (6% improvement between 2011 and 2013). [18] Recently the contribution of fuels other than ethanol has been on the rise **Error! Reference source not found.**). At the end of 2013, regulated parties had generated 2.62 million MT CO_2e in credits beyond compliance requirements (Yeh & Witcover, 2014b). While the LCFS has seen a large number of new low-carbon biofuel companies register under the program, and a reduction in carbon intensity ratings of conventional biofuels like ethanol, much greater emissions reductions will be needed to achieve the 2020 10% CI reduction target.

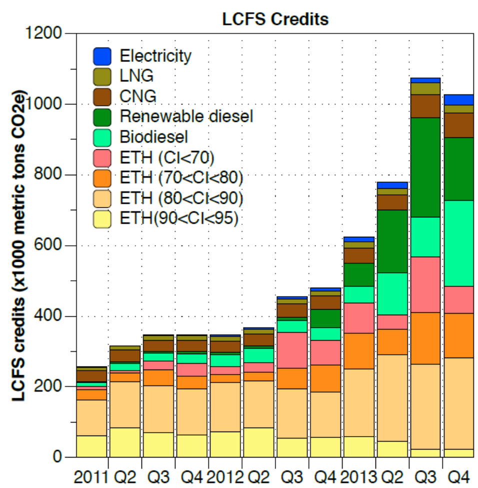

Figure 0-1. LCFS credit generation by fuel type (Yeh & Witcover, 2014b)

The LCFS shares program design features with familiar market-based environmental policies such as cap and trade programs for criteria pollutants, but differs in several notable ways. Well-known market-based mechanisms to control pollutants in the United States, such as the acid-rain trading program, are cap-and-trade programs that use tradable credits, or allowances, to limit the absolute level of a particular pollutant without dictating compliance mechanisms or strategies. Regulated industry therefore has substantial flexibility in meeting goals by installing pollution control technologies, shifting to cleaner fuels, purchasing allowances from

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[17] In 2014, the requirement for both gasoline and diesel pools was an AFCI 1% below the baseline.
[18] Credit shares from non-ethanol fuels were about 12% each for biodiesel and renewable diesel, less than 10% for fossil and biomass-based natural gas (CNG almost 8%, and LNG 3%), and less than 2% for electricity.

the market (relying on others to achieve reductions), or some combination of these. This flexibility increased policy efficiency compared to more traditional "command-and-control" methods. Similarly, the LCFS sets a performance standard and does not dictate specific compliance mechanisms or strategies, and permits compliance through several avenues, e.g., improving operational efficiency and shifting to lower-carbon production inputs, expanding or improving existing alternative fuels, purchasing credits from other regulated parties, or some combination of these. However, an LCFS does not limit the absolute level of emissions, but rather emissions per unit of energy expended. In addition, the LCFS creates an incentive for technologies below the target carbon intensity, whereas under cap-and-trade emissions face a cost regardless of their source. Because of this, the LCFS can create stronger incentives for low-carbon fuels (Sperling & Yeh, 2009) whereas cap-and-trade can provide for lower cost GHG reduction overall.

The LCFS determines and relies on the fuel CI ratings using lifecycle modeling of fuel production, delivery, and use. As the science of lifecycle analysis evolves, the policy should be updated to incorporate new information (balanced against the need to send a stable signal to investors about the value of their fuels). The need for updating holds especially for estimates of market-mediated contributions to lifecycle emissions, such as estimates of emissions associated with land use change, typically from biofuels (Witcover, Yeh, & Sperling, 2013).[19] Because the extent of land use change in a prospective world with biofuels relative to a world without biofuels cannot be directly observed, estimating land use change emissions requires modeling.[20] Estimated emissions from land use change from biofuels can be quite large, and occur when feedstocks displace some other activity, such as annual or perennial cropping (including food production), pasture for animals, or forestry. Some displaced activity can take place elsewhere and involve bringing new land into production or switching productive activities, often resulting in net emissions. Without proper accounting for land use change emissions, biofuels that require land will be overly incentivized by the carbon policy, since they appear to have greater carbon benefits than they actually do. The result is a mischaracterization of climate benefits or possibly even an exacerbation of climate change relative to business as usual. California's LCFS does account for land use change and continues to evaluate these effects as the science and lifecycle analysis evolves.[21]

[19] Other potential indirect effects of concern include impact on food prices, agricultural resource availability, and biodiversity (Melillo et al., 2009).

[20] Estimations often involve coupling models of economic equilibrium for agriculture and energy sectors with assessments of carbon emissions from land use transitions of specific types in specific locales.

[21] Administrative entities must also confront significant uncertainties about the carbon intensity of a particular fuel sold in the market and in determining CI ratings that send appropriate investment signals to the private sector. Uncertainties are unavoidable because emissions over the lifecycle of the fuel are estimated (not directly measured), and the models used for such estimations are sophisticated and include many assumptions. Uncertainties arise mainly from two sources: parameters in the lifecycle model, and the modeling approaches used. Some of the uncertainty can be mitigated with better data, increased modeling sophistication, and more granular definitions of fuel

Scale of Potential Emissions Reductions

Not surprisingly, the stringency of the standard strongly affects how much carbon abatement the LCFS ultimately can achieve. The current requirements of 10% AFCI reductions from 2010 levels by 2020[22] translate into 2020 target AFCIs of 89.06 gCO_2e/MJ for gasoline and its substitutes, and 88.23 gCO_2e/MJ for diesel and its substitutes (Figure 1-2). Carbon intensity targets for 2015 onward will differ from the originals, due to a California state court ruling that requires program re-adoption under revised procedures for environmental review: the 2014 and 2015 CI standards are frozen at the 2013 level of 1% CI reduction; CARB is expected to adopt a more back-loaded trajectory to the 2020 target, to soften the rate of decline from the 1% frozen target to the 10% required in 2020.[23]

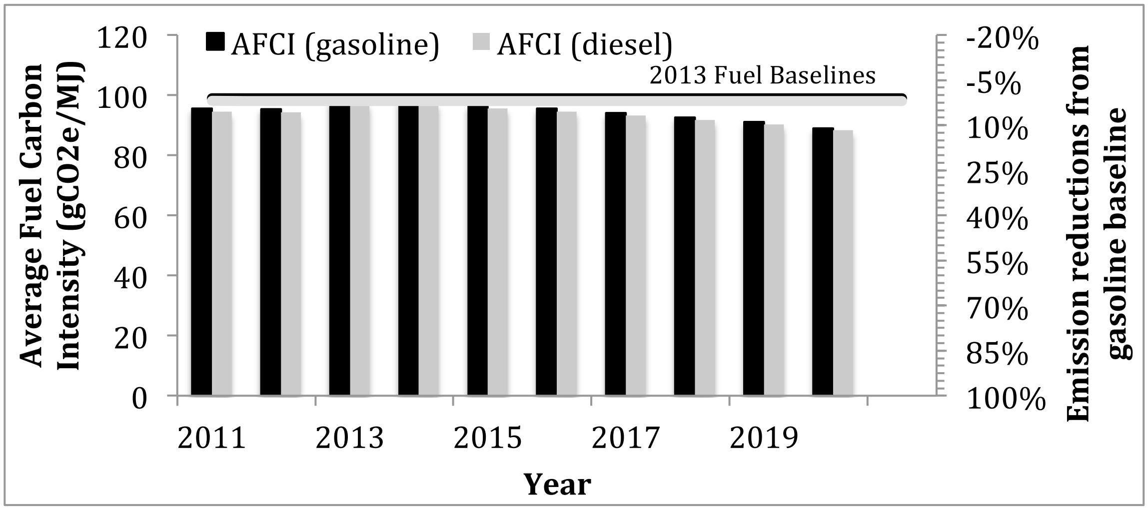

Figure 0-2. The Average Fuel Carbon Intensity of the fuel pool is regulated to decrease yearly, decreasing to 10% below the 2010 baseline fuel level by 2020[24].

A technology feasibility study by Yeh, Lutsey, and Parker (2009) indicated that fuel providers could likely comply with the 10% emission reduction standard using a multitude of fuel pathways. For compliance to be achieved, however, a number of technological advances will be necessary (Zhang, Joshi, & MacLean, 2010). One assessment of California's LCFS indicates that high penetration of hydrogen and electric vehicles coupled with continued de-carbonization of the electricity grid will aid emission reduction goals (Andress, Dean Nguyen, & Das, 2010). Meeting LCFS targets in 2020 would mean GHG emissions from California transport fuels in 2020

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pathways, but these steps can also increase the administrative burden. Unavoidable uncertainty derives from the need to make modeling choices, including those about projections of the future.

[22] As included in Title 17 CCR 95480.

[23] The current standard increases from 3% CI reduction in 2016 to 10% in 2020 in 1.5% increments. The new trajectory would include a 2% standard in 2016, 5% in 2018, and 10% in 2020.

[24] The increase in the carbon intensity standard from 2013 onward is due to an updated calculation in 2012 of the 2010 baseline CARBOB CI (reflecting the same percentage reductions from a revised baseline). This is an artifact of the update and not a decrease in policy stringency. CARB is expected to approve another update to the baseline calculation, to go into effect in 2016.

will be 4% below 1990 levels or 23% below 2005 levels.[25] The result falls between reduction potentials for 2020 compliance with the LCFS found in scenario modeling work done by Holland, Hughes, and Knittel (2009), which accounts for supply and demand in fuel markets as well as carbon market transfers (12% to 45% reductions from 2005 levels for pessimistic and optimistic scenarios respectively). Compared to one business-as-usual projection, 2020 compliance would achieve emissions reductions of almost 11% (**Error! Reference source not found.**).

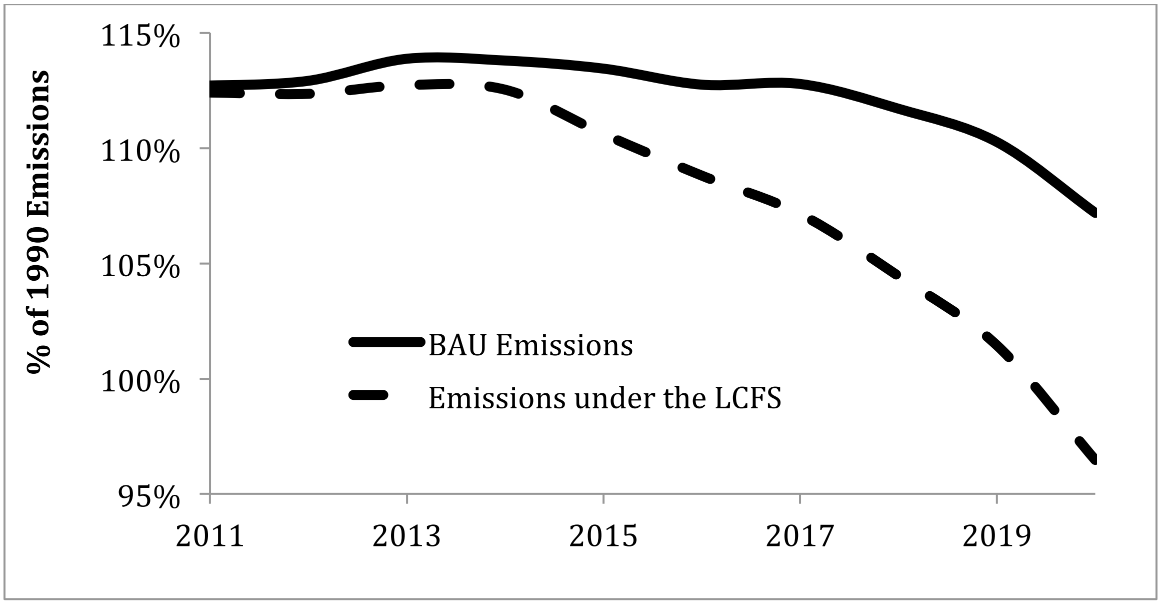

Figure 0-3. Emissions reductions from achieving the LCFS from one business-as-usual (BAU) projection (California Air Resources Board & Argonne National Laboratory, 2009; Yeh et al., 2013)

Cost Effectiveness

Several peer-reviewed studies alongside consulting reports have assessed costs and benefits of implementing an LCFS in California (Holland et al., 2009; Stonebridge Associates, 2012; The Boston Consulting Group, 2012; Yeh et al., 2009). The peer-reviewed studies on cost and benefits focus on different aspects of costs and benefits (private or public), and individual study estimates have ranged widely regarding carbon cost. A 2009 study estimated the cost to fuel providers of complying with the LCFS using only biofuels if cellulosic biofuels were in large-scale production, based on engineering costs (not accounting for market effects) (Yeh et al., 2009). The study results ranged from a benefit of $125 to a cost of $24/tonne CO_2, at petroleum fuel costs of $2 to $3 a gallon. The study noted that compliance costs would be higher when new technologies were emerging until volumes allowed learning and economies of scale that lower production costs. Another study estimated an average abatement cost – loss of consumer and producer private surplus – under a California LCFS between $263 and $903 per ton CO_2e (Holland et

[25] Using LCFS carbon intensity ratings (and building upon modeling work by Yeh, Witcover, and Kessler (2013)), we have back-calculated 1990 and 2005 transportation fuel emissions using LCFS methodology (obtaining emissions levels as they would have been accounted for under the LCFS).

al., 2009), with lower estimates associated with supply and demand being more responsive to fuel price.[26] Their model included gasoline and ethanol only, calibrated to 2005 conditions. Studies of a potential national low carbon fuel standard in conjunction with the federal Renewable Fuel Standard found aggregate net benefits for the United States from 2007-2035 equivalent to roughly $54 to $99 per metric ton of CO_2e abated (Huang, Khanna, Önal, & Chen, 2012). The large range in estimated abatement costs and benefits across studies is due to differing assumptions about the availability of low-carbon fuel and vehicle technologies, the cost of producing low-carbon fuels over time, the costs and benefits from displacing petroleum-based fuels, and assumptions about what policies beside the LCFS are in place.

Scientific studies have also examined the efficiency of intensity standards such as the LCFS, which regulate emissions per unit of output, often compared with alternative policy mechanisms such as carbon taxes, which target each unit of emissions. Holland et al. (2009) argue that the LCFS is less efficient in reducing emissions compared to a carbon tax, because it creates incentives for some emissions – those associated with low-carbon fuel technologies. That said, an LCFS is a more useful tool for incentivizing development of cleaner fuels from renewable resources when market failures prevent producers from realizing all their benefits (including climate benefits), and more direct policy tools are not available.

LCFS Credit Market

LCFS credit prices reflect and are influenced by a number of factors. In general, credit prices reflect differences in cost between the traditional fossil fuel and the highest marginal cost of low-carbon fuel needed to meet the standard. For example, if the last unit of fuel used to meet compliance is biodiesel, LCFS credit prices will reflect the cost difference between bringing biodiesel compared to traditional diesel fuel to the transport fuel market.[27] Under normal market conditions, current prices should reflect both current and expected future compliance costs since regulated parties can bank credits over time for future use.[28]

Error! Reference source not found. shows the history of LCFS average credit prices as reported to CARB in 2013 and the first half of 2014 spanning $30-$80 and variable volumes (Yeh & Witcover, 2014a). Prices in 2012 averaged $15; over the last six months from the date of this report, prices have shown some stability around $25/credit . The recent price decline is likely due to policy uncertainty about possible program amendments during re-adoption, including the compliance target trajectory from 2016 to 2019. Credits represent a MT of CO_2e saved or emitted

[26] One study (Boston Consulting Group, 2012) with higher cost estimates was critiqued for having narrow and questionable assumptions about current and future availability of low-carbon fuels, and for insufficient consideration of alternative fuel vehicle technologies (Weyant et al., 2013).
[27] Note this could just be cost of transporting fuel to California, if the fuel was already being produced for another purpose.
[28] Expectations about future fuel costs and policy stringency both shape expected compliance costs.

relative to the standard, and thus are not equivalent to cap-and-trade allowances, which refer to MT CO_2e emitted under the cap. The recent $25/credit translates to roughly one third of one cent per gallon of gasoline used for blending in 2014. The LCFS is revenue neutral, meaning the carbon cost it adds to gasoline is transferred directly to incentives (subsidies) for low carbon fuels. The LCFS can mean higher transport energy costs, if the low-carbon fuels used are more expensive than conventional fuels. Some low-carbon fuels, like biofuels, are currently more expensive than gasoline; others, like electricity and natural gas, are lower than gasoline and diesel on a per energy unit basis, but may require additional vehicles or infrastructure, with their own costs, before they can be used in the transport pool. For a discussion of how LCFS credit prices conceptually compare to carbon allowance prices in California's Cap-and-Trade program, see Yeh and Witcover (2014b).

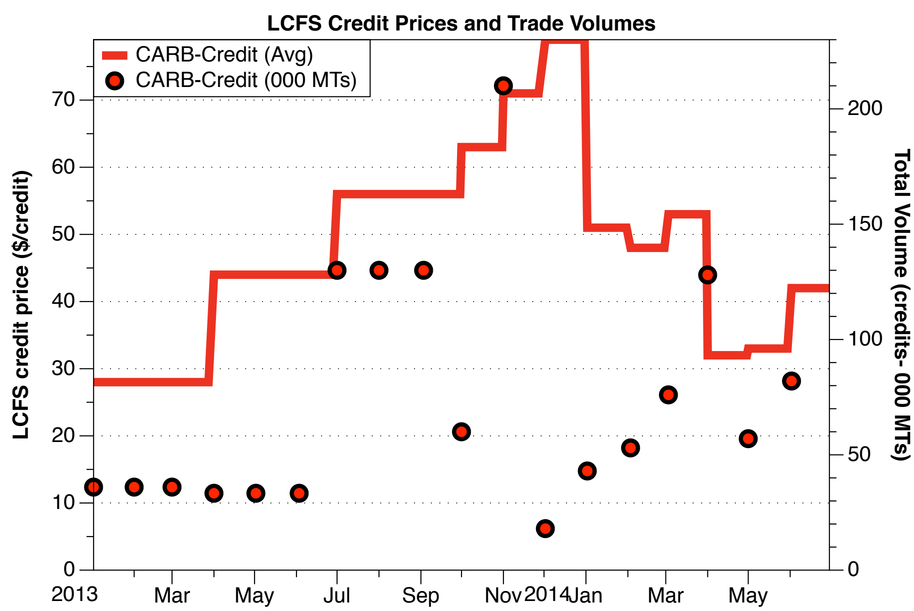

Figure 0-4. California LCFS credit prices (left axis) and traded credit volumes (right axis) reported to CARB

(Lade & Lin, 2013) show that the volatility of the LCFS can be substantially improved by setting a price cap on LCFS credit prices at an appropriate level, a measure that would also set a limit on compliance costs as well as program incentives for low carbon fuel technologies. By reducing the likelihood that high costs will lead to policy intervention with uncertain consequences, cost containment provisions can provide a more durable and stable LCFS credit market for low CI fuel investors. CARB is expected to adopt a price ceiling of $200 per tonne on credit transactions, and allow deficits to roll over (with a 5% annual interest applied to accumulated deficits) for up to 5 years in systemwide credit shortage situations. The proposal also involves calling a "credit clearance market" in systemwide deficit years, to facilitate trades between regulating parties holding deficits, and those wishing to sell credits. The buyers would commit to purchasing a share of available credits (pro-rated to their share of outstanding program deficits) at a price up to the price ceiling. A credit price of $200 would translate to about five cents a gallon of gasoline (blendstock, that is, before blending with ethanol for sale at the pump) in 2016 when a 2% CI reduction is required, and $0.24 per gallon in 2020 when a 10% reduction in carbon intensity is required.[29] The proposal leaves some ambiguity about costs if a deficit is not resolved within 5 years.[30]

Technological Feasibility

Alternative fuel pathways that may contribute to LCFS compliance such as liquid biofuels, fossil natural gas (NG), renewable natural gas (RNG), electricity and hydrogen each face technical, economic and market challenges. For example, the ongoing challenge for electricity is to continue expanding the consumer market for electric vehicles. For NG and RNG, the main challenges reside in deploying the necessary fueling infrastructure[31] and vehicles suitable for operation on natural gas,[32] while monitoring and mitigating methane leakage. For hydrogen, the challenge is to initiate and expand the market for fuel cell vehicles and induce investments in the retail infrastructure to serve those vehicles. For liquid biofuels, the challenge is primarily associated with the development and deployment of a commercial-scale low-carbon biofuels industry, with appropriate monitoring and mitigation of land use change and other potential unintended consequences.[33] All of these options will require significant and sustained private-sector investment, which the LCFS is designed to encourage. In each category, along with the challenges, there is some cause for optimism.

Electric drive vehicles, predominantly battery electric vehicles (BEV) and hydrogen fuel cell vehicles (HFCV), will have to overcome significant obstacles to become mass-market alternatives (McCollum & Yang, 2009). On the other hand, the experience with plug-in vehicles suggests that consumers may be willing to accept shorter vehicle range and different refueling methods; plug-in vehicles are showing

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[29] A deficit generated in 2016 that wasn't resolved until 2020 would translate to $0.29 on the roughly 726 gallons associated with that ton of carbon; the effect per gallon of gasoline sold would be spread over the large volumes. For instance, 1 million maximum carryover deficits from 2016 to 2020 in a pool of 13 billion gallons of gasoline would increase cost per gallon in 2020 for gasoline from $0.237 to $0.239.

[30] The noncompliance penalty in the proposal expected to be adopted sets a fallback maximum cost of $1000/deficit (about $1.44 per gallon for the 726 gallons associated with the deficit).

[31] RNG also needs a logistics infrastructure to collect the gas at landfills, biodigesters, and other sources of biomethane, to process the gas as needed, and to distribute it to dispensing stations.

[32] It is expected that CNG will continue to be adopted predominantly in heavy-duty applications, such as transit buses, port operations, etc.

[33] Large-scale applications of biofuels are expected to be eventually in heavy-duty vehicles and other modes of transportation such as commercial airplanes. To compete in the light-duty vehicle space, biofuels with much lower energy density than the petroleum fuels they replace will face a challenge associated with consumer acceptance (Collantes, 2010).

rates of consumer adoption higher than those exhibited by hybrid electric vehicles in their early stage of commercialization. While plug-in vehicles face a higher upfront cost, recent studies show these vehicles have a lifecycle ownership cost in many cases comparable to that of conventional vehicles (Burke, Collantes, Miller, & Zhao, 2014).

HFCV technologies have improved over the last decade to the point that some automakers are starting to lease vehicles in limited numbers. HFCVs have the potential to provide high consumer value in areas such as acceleration, reduced noise, etc., without compromising on range and refueling time. The main challenge for HFCVs is the difficulty and cost of deploying and coordinating hydrogen infrastructure concurrent with vehicle sales. California is pursuing a 'cluster' strategy, where stations are built in targeted areas where the early sales of HFCVs are expected to be strongest (Ogden, Yang, Nicholas, & Fulton, 2014).

Liquid low-carbon biofuels have seen some encouraging developments but the timing of emergence of a commercial-scale low-carbon biofuels industry is still uncertain. Stand-alone facilities to produce cellulosic biofuels could provide large volumes of low-carbon fuel (Parker, 2012), but will require additional policy support, investment, and time for scale-up and learning. In the meantime, a second trend has emerged in advanced biofuels: some cellulosic biofuel facilities are starting to be co-located with existing ethanol facilities to take advantage of existing infrastructure and local feedstock availability to lower costs. While limited in their total production potential, these "bolt-on" facilities could boost production and build the technical knowledge base for a future transition to stand-alone facilities (Fulton et al., 2014). Fuels from waste-based resources can be very low-carbon, and production is increasing, but the resource base is limited. Finally, small, incremental improvements in existing biofuel production technologies are now showing up under the LCFS that reduce carbon intensity ratings and generate credits on relatively large volumes of fuel.

Because the LCFS is technology neutral and rewards any emission-reducing changes in fuel pathways, it is difficult to predict what combinations of fuel volumes (with associated carbon intensity ratings) will be used for compliance over time, or when the constraints mentioned above could emerge as bottlenecks. That said, a recent supply study for potential Pacific Coast jurisdiction low carbon fuel standards through 2030 (dominated by California in terms of fuel volumes) found compliance did not rely on a breakthrough in any particular pathway, but did require substantial investment beyond a business-as-usual approach for some pathways (Malins et al., 2015). More specifically, the "bottom-up" fuel supply analysis entitled "Potential Low-Carbon Fuel Supply to the Pacific Coast Region of North America,"[34] found low-carbon fuel supply to the region could be sufficient to reduce the on-road transportation fuel AFCI in the region by 14%–21% by 2030, based on current

[34] Two coauthors of this chapter, Eggert and Witcover, provided technical assistance/overview to study authors.

policy assessments of fuel carbon intensities. The study identified various mixes of technologies that could achieve similar carbon intensity benefits, including existing and emerging cellulosic biofuels, electric vehicles, and natural gas, at various levels of market penetration informed by the existing literature.

The LCFS is technology neutral. This means that its compliance does not depend on the success or failure of a single feedstock or fuel type. Rather, the combination of credit prices and appropriately designed cost containment mechanisms can ensure that the market provides sufficient incentives for investments at reasonable cost to achieve the targets.

Administration

Like any policy that regulates complex industrial activities, the LCFS requires relatively large administrative resources for program development, implementation, and enforcement. As already mentioned, as the science of lifecycle analysis evolves and new information becomes available, the LCFS should be periodically updated. New fuel pathways need to be processed and procedures are needed to monitor existing pathways for significant changes that would affect CI ratings. Besides ongoing LCA calculations for new fuel pathways, program enhancements and changes include updating the average carbon intensity ratings of petroleum and alternative fuels (including land use effects) (Plevin, O'Hare, Jones, Torn, & Gibbs, 2010). CARB is expected to approve updates in carbon intensity ratings due to model updates, including lowered CI ratings for crop-based biofuels, due to lowered estimates for indirect land use change emissions from modeling updates). Administrative costs may be able to be streamlined, as familiarity with the program and analyses increases.

Other Considerations

The LCFS is a landmark policy to address GHG emissions from the transportation sector using a flexible, market-based mechanism to lower costs and encourage innovation. In this section we briefly discuss some opportunities for improving the policy.

Technology Innovation

The LCFS aims to motivate technology innovation that lowers transport fuel carbon intensity. To date, the policy appears to have incentivized or attracted fuels that make incremental improvements in carbon intensity reductions rather than large technological breakthroughs. Eventually, to meet the long-term climate goals of the program, new low-carbon fuel innovations that achieve substantial and scalable long-term carbon emission reductions will be necessary. Incremental improvements in a fuel’s carbon intensity can initially yield higher and safer returns on investment, since their use often does not involve development of additional infrastructure (which can be costly) or unfamiliar/untested techniques (which can be risky). As noted above, a price limit on LCFS credits can encourage more investment by strengthening the reliability of the price signal for low CI fuels, but also caps the size of the price signal. If additional investment (beyond the LCFS) is required for desired innovation, innovation policy should provide supplementary incentives to create conditions for nascent technologies to enter the market and compete with more mature technologies, and potentially realize early-stage learning without being crowded out by the more mature alternatives (Jenkins et al., 2012). Such policies include encouraging public and private research and development for both basic and applied sciences related to low-carbon fuels, other investment incentives, and policies that reduce the non-monetary barriers to low-carbon fuel deployment including permitting assistance, education, and outreach. For California's LCFS to succeed as an innovation policy, it should be coupled with policies that foster technology innovation beyond incremental improvements to existing technologies.

Mitigating Concerns about Shuffling and Leakage through Broader Jurisdictional Coverage

The fact that LCFS is a regional policy that impacts global markets creates the risk of leakage and/or fuel shuffling. Fuel shuffling under a region's LCFS may occur when a region that already makes use of a low-carbon fuel is instead incentivized to sell that fuel to the LCFS jurisdiction due to the premium they receive for sale in a market that values lower CI. The deficit of fuel in the originating region could then be made up by the displaced fuel in the LCFS jurisdiction. This is indeed a low cost way to comply with the regulation, and to the extent that it takes place, some of the carbon benefits accounted for in the jurisdiction would not be captured at a global level. One strategy to mitigate shuffling is to work to expand the coverage of the policy to account for regions that sell low-carbon fuels into an LCFS jurisdiction, or to move toward a broader, more global LCFS implementation (Kessler & Yeh, 2013; Meyer, Schmidhuber, & Barreiro-Hurlé, 2012).

Expanding an LCFS to more jurisdictions would increase the market for low-carbon fuels, at some point spurring additional fuel production as opposed to fuel shuffling, and provide opportunities to link markets for greater efficiency and lower cost compliance. To some extent, a version of this is already occurring through the partnership between California and the Pacific Coast jurisdictions Oregon, Washington, and British Columbia, Canada.[35] Harmonization of core principles and methodologies, and coordination across jurisdictions implementing an LCFS will be important to maximize program benefits and mitigate unintended effects such as fuel shuffling or market-mediated environmental and social consequences.

[35] Pacific Coast Action Plan on Climate and Energy, 2013, http://www.pacificcoastcollaborative.org/Documents/PCC%20NR%20-%20October%2028%202013.pdf

Mitigating Unintended Consequences

The LCFS and similar programs promoting biofuels and other alternative fuels can have impacts (both positive and negative) on food prices and the environment (for example, water availability or biodiversity). The policy should include mechanisms to monitor and mitigate unintended consequences. Evaluating indirect land use change is one such mechanism that can mitigate emissions from this source, as well as effects on food prices and biodiversity. More research and supplementary policies are needed to determine whether current measures are sufficient to safeguard against unintended consequences, and identify additional measures to be taken.

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The Cap and Trade Program and Fuels Under the Cap

Gustavo Collantes[36]

Key Findings

- As part of the economy-wide cap, starting in 2015, the California cap and trade program covers emissions from transportation fuels
- In a cap and trade program, the market price of carbon is variable. The California program includes mechanisms to address extreme carbon price swings.
- The cars drivers scrap or drive less in response to increased gasoline prices in California tend to correlate with the dirtiest vehicles in terms of local pollutant emissions. Thus, setting a price on carbon induces air quality benefits. There may be however equity implications of this result, to the extent that dirtier vehicles are owned by lower-income segments of the population—this questions needs further investigation.
- The interactions between cap and trade and other carbon policies makes are difficult to disentangle. More research is called for.
- Cap and trade does provide a backstop policy that ensures that emissions will not surpass state goals even if other policies are less successful than anticipated
- At expected early carbon prices before the program expanded to transportation fuels (while this report was written), the price of gasoline was estimated to increase by $0.10 to $0.15 per gallon. As the program has expanded to transportation fuels, the carbon price of per gallon of gasoline has amounted to about $0.11.
- At these lower estimated prices, the long-run carbon emission reductions from transportation would exceed 3.5 million tons of CO_2e per year

Background

As part of the AB 32 carbon-reduction legislative initiative, California is implementing one of the broadest GHG cap and trade programs in the world. The program aims to reduce GHG emissions throughout the state's economy over a period of eight years starting in 2013, and contributing to the goal of bringing emissions by the year 2020 to 1990 levels (CARB, 2014).

Cap and trade is an accepted and increasingly popular environmental policy tool available to regulators. Cap and trade programs have been implemented in Europe,

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[36] The drafting of this chapter benefitted from significant contributions and thoughtful reviews by Dr. James Bushnell, Derek Nixon, and Anthony Eggert.

the Northeastern U.S. (Regional Greenhouse Gas Initiative), California, Quebec, New Zealand (Center for Climate and Energy Solutions (C2ES), 2014), and in five cities and two regions of China (Kossoy, 2013). Carbon dioxide and other heat-trapping pollutants are not the only emissions to have been regulated through cap and trade; local pollutants including sulfur dioxide and nitrous oxides are also subject to active and successful regional cap and trade regulation policies.

When forming a cap and trade program, a limit (the "cap") on total allowable emissions over a certain time period (typically one year) is set. This cap is expressed as units of emissions and for each unit a carbon permit is created. In the case of California, the unit is equal to one metric ton (MT) of carbon dioxide equivalent (CO_2e). Then, parties regulated under the program are allocated or acquire permits, or allowances, by means of mechanisms described below. These regulated parties have emissions measured during each compliance phase[37] and at the end of each compliance phase they are required to surrender allowances equivalent to their measured emissions. Since each regulated party must acquire permits equivalent to its measured emissions and the sum of the allowances surrendered by the aggregate of all regulated parties is equal to the cap, this process ensures that total emissions do not exceed the cap, thus achieving the program's goal.

Allowances may be transferred from one party, to another (the "trade") under cap-and-trade programs. Each covered regulated party faces a choice of reducing emissions or acquiring allowances to offset its emissions. The process of allowance trading thereby sorts regulated parties into those with lower-cost abatement options who are more likely to choose to reduce emissions, and those with higher costs of abatement who are more likely to choose to purchase allowances. In theory the market clearing allowance price will, through this process, converge to the marginal cost of abatement[38] and provide for the lowest cost of achieving the goal.

Features of California's Cap and Trade

There are several key design choices that characterize a cap-and-trade program. These choices include the method for distributing allowances to regulated parties, methods for controlling the cost of allowances, and ways to account for "spillover" effects on emissions in neighboring regions. The following sub-sections summarize the key features and design elements of the cap-and-trade program implemented in California.

[37] The first compliance phase for 2013-2014 is two years long, while phases are three years long thereafter.
[38] The marginal cost of abatement is equal to the most costly of all the abatement strategy actually pursued by regulated parties.

Program Design: Who Are The Regulated Parties?

The scope of the regulation, in terms of industries that fall under the cap, has evolved in two phases. Since 2013, California's cap has been applied to carbon emissions from the electric sector, some industrial and agricultural sources, and oil refining (CARB, 2013) affecting sources responsible for about 35% of California's GHG emissions (Center for Climate and Energy Solutions (C2ES), 2014). The program expanded starting in 2015 to include transportation fuels and natural gas distribution; an element of the program known as "fuels under the cap." At that point, the program will cover sources responsible for 85% of the state's GHG emissions.

The choice of what entities to regulate within a sector often comes down to whether to regulate "upstream" or "downstream." Given that California's program is limited in geographic scope, upstream taxes on producers may increase leakage, or emissions in non-capped regions by competitor upstream firms (J. B. Bushnell, Erin T. Mansur, 2011).[39] Concerns about leakage shaped California's regulation strategy, primarily in how permits have been allocated for certain sectors (CARB, 2013).

Program Design: Distribution of Permits

The total monetary value of carbon markets dwarfs that of previously implemented cap-and-trade markets. The market value of annual emissions allowances in California will exceed $4 Billion. The method for distributing the allowances, as well as the disposition of any revenues from allowance sales, therefore carries large implications for both economic efficiency and equity (J. B. Bushnell, Chong, & Mansur, 2013; Goulder, 1995; Goulder, Hafstead, & Dworsky, 2010; Goulder, Parry, Williams Iii, & Burtraw, 1999; MacKenzie & Ohndorf, 2012). There are three general methods for distributing allowances; California has chosen different approaches for different GHG emitting sectors in order to strike a balance between helping regulated firms and consumers adjust to the cap, minimizing leakage to other jurisdictions, and directing allowance revenue to desired public investments.

Method One: Grandfathering

The method of allowance allocation known as *grandfathering* provides regulated entities with a free annual allocation of carbon permits equal to a fixed percentage of their pre-cap historical emissions. The allocation is not tied to specific current production levels, so that free permits do not implicitly and unintentionally subsidize current output. This separation between allocation and production decisions ensures the full price signal is realized by the firms (Fowlie & Perloff, 2013; Reguant, 2008). In theory, this method of allocation does not distort the

[39] Leakage refers to the unintended displacement of emissions from the regulated jurisdiction (e.g. the state of California) to unregulated jurisdictions.

abatement decisions of regulated entities and can therefore provide for least-cost carbon reduction.

If the amount of allowances that are freely allocated approaches the total of capped emissions, regulators have limited flexibility for adjusting capped emissions. Allowances in excess of capped emissions leads to a collapse in the value of allowances towards the lowest possible carbon permit price allowed under the cap and trade program. A collapsed or unpredictable carbon price significantly weakens the carbon signal in the economy, cutting off the incentive for investment in longer-run and cost-effective abatement actions.

Grandfathering constitutes a (potentially large) transfer of money to regulated industry from government, who would have otherwise auctioned allowances. This transfer of money to regulated entities is sometimes referred to as *windfall profits*, and was evidenced in the European emissions trading program (Sijm, Neuhoff, & Chen, 2006).

Method Two: Benchmarking or Output-Based Allocation

A second method in which allowances are freely allocated links the allocation quantity to the economic activity of the regulated entities that receive the allowances. Such a process is known as "updating," in reference to the fact that the quantity promised to the regulated entity is contingent on its actions, unlike grandfathering where allocations are based upon past history. Output-based allocation is usually implemented to discourage regulated entities from reducing their production or moving it to unregulated regions. Allowances are allocated in ways that reward regulated entity for each unit of output (e.g. ton of cement produced or gallon of gasoline refined) that is produced locally.

In order to determine the allocation for a given regulated entity, allocations are usually based upon an industry standard benchmark. For example, a cement producer would be awarded, per each ton of cement produced, allowances equal to (or a fraction of) the industry-wide average CO_2 per ton of output. In this way firms have an incentive to reduce their intensity (amount of CO_2 per ton of output) while also maintaining their output (tons of output). If they can reduce their intensity sufficiently below industry average, they can be awarded extra allowances. Because regulated parties have an incentive to maintain or increase production, updating also limits the impact of carbon prices on products in industries subject to updating (Fischer, 2004; Fowlie, 2010). In this way, benchmarking provides incentives very similar to intensity standards, such as the Low Carbon Fuel Standard (discussed in Chapter 5). A drawback of this approach flows from this price effect; end-use consumers are not affected by the "cost'' of carbon and therefore are not incentivized to adjust their consumption. This, in turn, can raise the overall cost of achieving the goals.

Method Three: Auctioning

The first two methods award allowances at no cost to regulated firms. By contrast, auctioning requires regulated parties to purchase their needed allowances from the regulatory jurisdiction, thereby generating public revenue. Auctioning requires regulated parties to submit bids to buy fixed quantities of allowances sold by the government during periodic (e.g. annual or quarterly) auctions. A benefit of this approach is that revenues can be used to further reduce greenhouse gasses from uncapped sectors, or to offset other taxes that can profit a net benefit for the economy. This latter effect is referred to as the "double dividend" from auctioning or carbon taxes. It also avoids the problems associated with the two previous methods and does not require the administrating entity to make difficult and often contentious decisions about allowances distribution.

California's Allocation Methods

California utilizes all three methods of allowance allocation. The methods differ by sector. A large majority of emission allowances to industrial emissions are allocated based on output under the justification that those industries are exposed to trade from unregulated regions. The fraction of industry-wide emissions that is awarded allowances is scheduled to decline over time. The remaining carbon compliance obligations for this sector must then be met through quarterly permit auctions generating revenue (Center for Climate and Energy Solutions (C2ES), 2014).

Electricity and natural gas utilities are treated differently than other sectors. While the electricity generators are the covered entities under the program, allowances are directly allocated to utilities under a grandfathering metric and are then sold at auction to generators. The California Public Utilities Commission has jurisdiction over the impact that allowance prices associated with these allocations may have on rates (CARB, 2013). Much of the allowance revenues are used to offset increases in utility rates due to carbon costs.

In the transportation sector, the majority of allowances for emissions associated with fuel refining are allocated under an output-based approach. Allowances to cover the emissions associated with tailpipe emissions from the transportation sector will be auctioned by CARB. These comprise the bulk of the allowances for this sector. Therefore while emissions associated with refining are not expected to be reflected in retail gasoline prices, part of the emissions costs associated with fuel combustion will be included in gasoline prices providing an incentive to consumers to purchase more efficient vehicles and drive more efficiently.

Program Design: Price Stability Mechanisms

Until California's cap has greater operational experience, it is difficult to project the exact cost of reducing emissions incurred by the capped entities. This introduces uncertainty about the projected prices of permits. To the extent it is less expensive over time, the price of permits will be driven down. If the permit price drops significantly, it might be an indication that factors such as electricity import reshuffling are dominating abatement and that the cap-and-trade program isn't driving significant abatement efforts (Anderson & Di Maria, 2011). Alternately, to the extent marginal carbon abatement becomes more expensive, permit prices would increase to reflect (and motivate) more expensive abatement strategies. This could shift carbon commodity prices quickly in the economy or at high enough levels that could invite political intervention, which would in turn create uncertainty about the program and discourage investments in low-carbon technologies and strategies (Borenstein, Bushnell, Wolak, & Zaragoza-Watkins, 2014).

Two regulatory features of California's cap and trade help to prevent excessively high and low prices. In previous simulations, these features substantially improve the efficiency of cap and trade regulation (Burtraw, Palmer, Bharvirkar, & Paul, 2001; Fell, Burtraw, Morgenstern, & Palmer, 2012; Pizer, 2002).

Establishing a Floor for California's Carbon Price: Adjustable Auction Quantity

California has set a minimum carbon permit price that is currently increasing at 5% plus consumer inflation from 2013 to 2020. This minimum price is called the auction reserve price. California enforces this minimum price through an adjustment in the quarterly permit auctions for the permits that are not freely allocated (CARB, 2013). In each quarterly auction, market participants bid for permits, and these bids and corresponding quantities are ordered from highest to lowest. If the bids ordered from highest to lowest ever fall below the price floor before matched up with all available permits, California restricts the permit sale to the quantity of bids submitted at prices at or above the reserve price. This leaves surplus permits to be sold in future auctions, but ensures permits are sold only at or above, the reserve floor. The mechanism effectively establishes a floor price on allowances as long as there is sufficient demand for allowances through the quarterly auctions.

Establishing a Soft Ceiling for California's Carbon Price: Allowance Price Containment Reserve

California has set aside 5% of the total carbon permits available in the cap and trade into a *Price Containment Reserve*. This 5% of permits is equally divided into "low," "medium," and "high" priced permits at 2013 prices of $40, $45 and $50 that have escalated in 2014 and beyond at 5% per year plus inflation. If marginal abatement was very costly for regulated entities, and demand for permits could result in quarterly auction prices above the price containment reserve value, the lowest cost containment reserve permits are sold into the auction until the last remaining bid equals $40. If demand continues to be strong at high price levels and all $40 permits are exhausted, then $45 containment permits are sold until the market clears at $45.

Should the $45 permits be exhausted, the same rule determines the sale of the $50 permits. Provided the $50 permits are never exhausted, the containment reserve will be successful in creating a "price ceiling" at or below $50.

Program Design: Complementary Policies

A final consideration in setting a cap depends on pre-existing policies or new policies implemented at the same time as the cap and trade. For example, in California's program, transportation fuels are included under the cap, but transportation emissions are also affected by other programs, including the Low Carbon Fuel Standard (LCFS, Chapter 5), the Sustainable Communities Strategies (SB 375, Chapter 4) and the federal Clean Cars Program (Chapter 2). We refer to these other programs as *complementary policies*. Among all of the GHG policies implemented under AB 32, California's cap and trade program provides a backstop; it helps to ensure that the state's 2020 emissions reduction goals are met, even if other policies fall short. To the extent the other programs succeed in reducing (or fail to reduce) emissions by their target levels, the reductions needed under the cap decreases (increases). This is achieved through an expansion (reduction) in the number of permits available for compliance. If other programs do not meet their carbon reduction quotas, fewer permits are introduced into the cap, and with fewer permits, prices of permits increase, motivating greater carbon reductions.

Cost Effectiveness

Cap and trade does not mandate the use of any particular carbon-reducing strategy to comply with carbon emissions limits. Instead, it promotes discovery of the least-cost strategies. If all covered entities were efficient and had the necessary information, then trade between these entities should lead to the adoption of abatement strategies with the lowest cost. Complications can arise when a market-based regulation such as cap-and-trade is imposed across industries or sectors that face different incentives. When factors that distort the choices of a regulated entity away from cost-minimization (for example, market power or utility regulation) are present, the efficiency of the cap-and-trade will likely be diluted. The efficiency of cap-and-trade can also be diluted when other policies, such as California's complementary policies, reduce the flexibility of regulated entities in their choice of abatement strategy.

Cost effectiveness is also affected by the fact that the cap is regional rather than global. This is not a flaw of the state's program, but rather a consequence of the inability of other regions to implement similar programs. There are two ways in which this can prevent the program from achieving least cost abatement. First, and trivially, it is possible that the least expensive abatement strategy can be realized not in California but in other regions of the world. Recognizing this, California allows out-of-state carbon "offset" credits, or special projects outside the cap that result in measured carbon reductions of one ton, and thus are counted as equivalent to a carbon permit, to count for a portion of a regulated entities' annual compliance obligation. Second, in the electricity sector, California's electricity grid is connected to other regions of the Western United States and Canada; some of the higher-carbon imported electricity that had been serving in-state loads may be swapped for lower-carbon electricity from other out-of-state power plants—this process is commonly known as *reshuffling*.

Technological Feasibility

Since the exact method used for compliance is flexible, covered entities are expected to discover and utilize the feasible means of compliance that best suit them. Unlike other directed measures (e.g. a mandate for a certain quantity of solar generation), cap-and-trade therefore provides the flexibility to ensure feasible compliance.

The main concern with the feasibility of cap-and-trade relates to its implementation by regulators. As a general instrument, cap-and-trade has been applied in several contexts, including a U.S. market for SO_2 and the Emissions Trading System market for CO_2 in the European Union. One concern has been the ability of regulators to accurately and cost-effectively measure the emissions of the regulated entities. Since California's cap-and-trade covers only direct emissions and not lifecycle emissions (discussed at length in the chapter on the Low Carbon Fuel Standard), measurement of emissions, with two exceptions has been reasonably straightforward. The bulk of CO_2 emissions from most industries results from the burning of fossil fuels, and the conversion from units of fuel to units of CO_2 is tractable.

Two exceptions complicate the accuracy of measurement. First, electricity imports into California are regulated under a policy where the importer (or *first-deliverer*) is responsible for identifying the source of its imported electricity and its associated GHG emissions. In an integrated electricity grid, it is very difficult to confirm the source of an individual flow of power into the state, so the matching of specific plants to specific consumers is largely an accounting exercise. Regulated entities can choose to claim an unidentified source and accrue an emissions obligation according to a default emissions rate, which at currently .428 tons/MWh, is equivalent to a reasonably efficient natural gas combined cycle plant. Firms may also choose to switch their imports from higher carbon sources (e.g. coal power plants) to lower carbon options. Even though the California share of Western U.S. emissions would go down under such an arrangement, total emissions in the West would remain unchanged if the output of the coal plant were consumed in (or *reshuffled* to) another western state.

Second, the use of offsets creates additional measurement challenges. Unlike the measurement of covered sources, offsets pay firms to reduce emissions from an assumed business as usual baseline. To the extent that such entities would have reduced those emissions regardless of the offset payment, the offset can be seen as paying for *non-additional* reductions. In other words the offset did not achieve true additional reductions in CO_2 emissions beyond business as usual. These questions affect, at least indirectly, the transportation sector to the extent that they can result on lowering carbon prices to artificially low levels.

Administrative Burden

The best available measure of the administrative burden of all of AB 32, including cap-and-trade, to the various state's departments charged with AB 32 implementation is the *Common Carbon Cost*. This includes current operating expenses and loan repayments for the initial startup of AB 32 legislation. For the (single) fiscal year 2013-2014, CARB measured a cost of administering AB 32 of $50 Million. Of this, $40 Million came from operational expenses, and $10 Million was loan repayment. This initially seems substantial, but this is equal to $0.14.5 per ton CO_2e for firms paying by the ton, and $0.124 per gallon by transportation firms paying by the gallon. Roughly 250 regulated entities pay the administrative fee in proportion to their carbon emissions.

California's Cap and Trade and the Transportation Sector

With the transportation sector the single largest carbon emitter covered under the cap and trade program, it is important to understand the cap's impact on transportation emissions.

Mechanisms Through Which Cap and Trade Can Reduce Transportation Emissions

Pricing policies such as cap and trade send a price signal that induces behavioral adjustments on the part of the regulated parties and other sectors of the economy, including consumers. The degree of such adjustments will depend on a myriad of factors, including the net strength of the price signal (once the effects of other overlapping policies such as the Low Carbon Fuel Standard are accounted for), the state of the economy at a given point in time (for example as measured by GDP), the income of a particular household, the particular characteristics of a business, etc. The following are representative of the types of incentives that could result from including transportation fuels in the cap and trade program:

- Increase in the incentives for the production and purchase of more efficient or alternative-fuel vehicles
- Incentives to drivers to drive more efficiently
- Incentives to drive less, for example by shifting to lower-carbon modes of transportation (bike, walk), or discouraging moving to auto-oriented housing
- Incentives for investments in infrastructure that supports lower-carbon mobility, such as transit-oriented housing developments, bike lanes, etc.
- Incentives for the production and use of lower carbon fuels.

These are discussed in further detail below.

Shift Towards Purchases of Efficient Vehicles

As mentioned above, one expected effect of cap and trade is to induce consumers to purchase more fuel-efficient vehicles, as the price signal will increase the per-mile cost of vehicle operation proportionally to the carbon efficiency of vehicles. This outcome has been documented in Li, Von Haefen, and Timmins (2008), Klier and Linn (2010), Ross Morrow, Gallagher, Collantes, and Lee (2010), and Busse, Knittel, and Zettelmeyer (2013). Ross Morrow et al. (2010) showed that a carbon pricing program for moderate allowance prices such as in California, would not alone induce significant adoption of new technologies such as plug-in vehicles to the extent that the cost of these technologies is much higher than that of conventional vehicles. Pricing would however provide initially modest additional incentives for consumers to consider adopting these new vehicle technologies. Over time, even if the incentive remains the same, consumers will be increasingly likely to adopt, as the cost of the new technologies comes down. Busse et al. (2013) also found that increases in gasoline prices in California from 1999 to 2008 induced Californian consumers to purchase more highly fuel-efficient cars while reducing significantly the market share of new vehicle models in the lowest fuel efficiency group.

A potential concern about the effectiveness of cap and trade in inducing adoption of more efficient new vehicles is whether consumers adequately factor the expected savings into their purchase decisions. Previous empirical research provides evidence that consumers do indeed consider future fuel consumption when purchasing new (and used) cars. Busse et al. (2013) find that consumers roughly equate future fuel consumption costs to their cost of borrowing money to pay for cars (APR). Dreyfus and Viscusi (1995), Goldberg (1998), Verboven (2002), Espey and Nair (2005), and Sallee, West, and Fan (2010) come to similar conclusions. Previous studies did not account for the situation in which gas price increases were paired with complementary policies, as is the case with the price signal from fuels under the cap.

As mentioned earlier, it is currently unclear what the net impact of the cap and trade program on new vehicle purchases will be, since pre-existing policies addressing new-car fuel carbon efficiency already exist in California and at the national level. Incentives such as the California Clean Vehicle Rebate Program (CVRP) also encourage fuel-efficient new vehicle purchases. It is possible that these complementary policies will push fuel efficiency beyond the levels that a gasoline price effect would have achieved. However, it is the case that a carbon price would make achieving the goals of these other policies more likely by better aligning the economic signals to consumers as they make decisions about what vehicles to purchase.

Increased Fuel Economy of the Vehicle Fleet

There are also behavioral shifts that result in effectively increasing the average fuel economy of the vehicles used in response to cap and trade. As the price on carbon is reflected in the price of gasoline and diesel in 2015, this can be compared to historic increases in gas prices for other reasons. The first mechanism by which cap and trade influences existing fuel efficiency is through a shift by multi-vehicle households towards using their more efficient cars. Knittel and Sandler (2013) found that from 2000 to 2008, Californian multi-vehicle households increase miles driven with their fuel-efficient vehicle(s) by 6% for every 5-cent increase in gas prices.

More significantly, increasing the per-gallon price of gasoline increases the rate at which consumers scrap (often older) vehicles with lower fuel economy. These vehicles tend to be responsible for higher emissions of criteria pollutant (NOx and CO) that contribute to air pollution and regional health effects. Li et al. (2008) found increases in gasoline prices, as will happen under California's cap and trade, increases scrapping of older low fuel economy vehicles. Similarly Knittel and Sandler (2013) found older cars with low fuel economy become more likely to be scrapped as driving costs increase (e.g. due to gasoline price increases) and higher fuel-economy vehicles, and especially newer cars become less likely to be scrapped.

Increased Adoption of Alternative Fuels

The Low Carbon Fuel Standard (LCFS) is the primary policy aimed at introducing alternative low-carbon fuels into the California market. Cap and trade may still provide additional incentives for greater volumes of alternative fuel production if the binding LCFS targets are exceeded: cap and trade provides a market in which conventional fossil fuels may become more expensive relative to lower-carbon fuels. While the LCFS requires a full lifecycle accounting of emissions, certain designated low carbon fuels are assigned a zero-emissions factor (Borenstein et al., 2014) under the California cap and trade program. Like the Clean Vehicle Rebate Program's influence on new car purchases, the interaction of the LCFS and cap-and-trade will make it difficult to assess the precise influence of the latter on alternative fuel supply.

Reductions in Fuel Consumption

Independently of vehicle efficiency, cap and trade, through its effect on fuel prices, also directly influences consumers to reduce their consumption of fuel. This outcome has been confirmed by empirical research. The greater the price elasticity of fuel demand, the greater this response is. Research shows that gasoline demand is very price inelastic in the short run, at around -0.1, and that this elasticity has further decreased over the last two decades (Graham & Glaister, 2002; Small & Van Dender, 2007).[40]

Davis and Kilian (2011) and Li, Linn, and Muehlegger (2012), find tax-related gasoline price increases may have a stronger impact than random external price shocks due to the expectation that a carbon tax will permanently increase gasoline prices for the indefinite future. To the extent that cap and trade provides a relatively stable signal on the price of gasoline, then consumption may be more elastic than estimated in the literature.

Because cap and trade may induce consumers to make changes in their travel behavior that take longer to implement, *long-run* elasticities are also relevant. The literature survey by Graham and Glaister (2002) found long-run price elasticities of fuel consumption around -0.71 to -0.84. This long-run effect is likely an aggregation of reduced vehicle miles traveled (VMT) and other effects such as changes in vehicle.

Ross Morrow et al. (2010) found, for the case of a national carbon pricing policy, the expected allowance prices would induce significant emissions reductions in the power sector, but would induce relatively small effects on vehicle fuel consumption. On the other hand, the success of the other complimentary policies would also reduce the impact of cap and trade on petroleum fuel purchases. As drivers adopt more fuel-efficient vehicles, they will be less sensitive to changes in gasoline or diesel prices.

Additional Benefits of Placing Transportation Under the Cap

Previous research has shown that the inclusion of the transportation fuels sector in the California cap and trade program will likely have positive equity outcomes. One of the benefits of including transportation fuels within cap and trade is that the decreased use of inefficient old vehicles, and decreased VMT in lower-income neighborhoods disproportionately reduce emissions of other co-pollutants. Knittel and Sandler (2013) found that in California the dirtiest vehicles in terms of local pollutant emissions significantly overlap the cars drivers scrap or drive less in response to increased gasoline prices. This means that by setting a carbon price, there are substantial drops in particulate matter, ozone (through nitrous oxides) and other local pollutants. The literature establishing a causal link between local pollutants and adverse health impacts is substantial, including impacts of particulate matter on fetal growth and pregnancy (Currie, 2011; Šrám, Binková, Dejmek, & Bobak, 2005) the impact of traffic congestion on mortality (Levy, Buonocore, & Von Stackelberg, 2010), and the link between elevated ozone levels and mortality (Ito, De Leon, & Lippmann, 2005).

[40] A price elasticity of -0.1 means that demand is expected to decrease (increase) by one percent for every 10 percent increase (decrease) in fuel prices.

Potential Carbon Savings from Transportation's Inclusion in the Cap

Fuel prices are the channel through which cap-and-trade impacts GHG emissions reductions in transportation. As the allowance price rises, fuel prices are expected to rise. The relationship is expected to be roughly $0.10 a gallon of gasoline for each $10 increase in allowance prices, assuming that most of the increase in cost is passed through to the pump. Increased fuel prices in turn impact the choice of vehicle purchases as well as the amount of VMT. The magnitude of carbon reductions depends on two factors of the actual cap's implementation and realized prices.

Carbon Savings Factor One: Permit Price

First, transportation fuel carbon reductions are driven by the carbon price. If carbon prices are high, conventional fuel prices increase more, and this translates into greater adjustments. Borenstein et al. (2014) find that over the course of the program, it is most likely that carbon permit prices will remain low at the price floor. They find a small likelihood that permit prices will be somewhere between the floor and the ceiling, mostly because there is limited carbon reduction possible in this range of prices. There is a not-insignificant chance, however, that a combination of strong economic growth and other factors including market manipulation could conceivably drive permit prices to the ceiling. These two (approximate) permit prices are shown in Table 0-1.

Carbon Savings Factor Two: Complementary Policies

A key source of uncertainty regarding the cap's estimated reductions in transportation carbon emissions is the degree of policy redundancy. It is possible that complementary policies may result in carbon savings that would have otherwise (in the absence of complementary policies) been achieved through the cap. Under this case, the cost of carbon abatement would be in excess of the marginal cost of abatement that could be achieved with a cap and trade program. Knittel (2014) refers to this as "out of the money" abatement.

For example, consider that the average new vehicle fuel economy increases due to a fuel economy standard and simultaneously fuel prices increase due to a cap and trade program. The attribution of the carbon savings is then somewhat arbitrary as the standard is coincident to the regulation that raises fuel prices. To the extent that abatement from complementary policies changes the responsiveness of the transportation sector to price signals, past estimates of this responsiveness, or price elasticities, may be less reliable to project changes in fuel demand in response to permit prices. For example, if consumers are driving much more fuel-efficient cars due to a new vehicle fuel economy standard, then the price impact will be diluted as the per-mile cost of driving will be lower.

Specific Estimates of Carbon Savings

Until specific realizations of permit prices and complementary policy-influenced fuel price elasticity are realized, it is difficult to project a specific amount of carbon reduced by the transportation sector. Table 0-1 shows, on the left specific elasticities, as found by past empirical studies. In the main portion of the table are estimates of annual transportation sector MMTCO2e based on permit prices of $13, or the 2013 floor price, $55, or the 2013 ceiling price, and an arbitrary permit price halfway between the two. These estimates assume that the entire cost of permits is passed on to consumers as increases in fuel prices and thus represent upper-limit estimates for a given permit price.

These figures are calculated in three steps. First a gasoline elasticity parameter is chosen from the literature (the rows in Table 0-1). Then a permit price is converted into a percentage increase in gasoline prices above current levels (the columns in Table 0-1). Second, by definition, the elasticity can be multiplied by the percentage change in price to get the percentage drop in fuel consumption. This is translated into a decrease in fuel consumption and emissions (emissions per unit of fuel are essentially fixed) by multiplying this percentage by total 2013 gasoline consumption.

Table 0-1. Estimated annual reductions in emissions from transportation fuel, for different permit price scenarios (million metric tons per year)

Permit Price	$ 13	$ 32	$ 50
Increase in gasoline cost	$0.11	$0.26	$0.41
Price Elasticity and Studies			
Short-run			
-0.1 Estimate: (Hughes, Knittel, & Sperling, 2008; Lin & Prince, 2013)	0.4	1.0	1.6
-0.2 Estimate: (Davis & Kilian, 2011; Rivers & Schaufele, 2012)	0.9	2.0	3.1
-0.4 Estimate: (Li et al., 2012; Rivers & Schaufele, 2012)	1.7	4.0	6.2
Long-run			
-0.8 Estimate: (Graham & Glaister, 2002)	3.5	8.1	12.4

The best estimates of the additional price to transportation fuels at current permit levels are a $0.10 to $0.15 increase in the price of gasoline (Borenstein, 2014b; Borenstein et al., 2014).

Best Cap and Trade Policy Practices and Features

The California cap and trade policy has many features that will make it an effective cap when including the transportation sector. Additional features will make the cap and trade more robust and ensure a low cost in meeting AB 32's carbon targets.

Ensuring Transportation Fuel's 2015 Entrance Into the Cap

One of the most important features of any regional cap and trade is its broad coverage of as many sectors of the economy as possible. The greater the coverage, the more chances to find lower cost carbon reductions. Transportation fuels and natural gas distribution have been added as covered sectors starting in 2015. This may result in significant carbon reductions that make the goals of AB 32 easier and more cost-effective to achieve across all sectors.

Any proposal to delay the entrance of transportation fuels into the cap would reduce the number of opportunities for low-cost reductions, and thus total carbon savings coming from the transportation sector. With AB 32's firm carbon emissions targets, this would increase the costs to other sectors. To the extent some of the carbon savings that would then be required to be reached from other sectors is more expensive than potential transportation carbon savings, the economy-wide cost of AB 32 1990 target compliance would increase, assuming the cap is not tightened with the inclusion of transportation. The converse is not true: if transportation is included and has expensive carbon abatement, then other sectors will reduce carbon further, and at worst AB 32 will maintain the same cost as before to achieve the carbon targets.

Strengthening Cost Containment Reserve

The Allowance Price Containment Reserve (APCR), as described above, is an account where the state sets apart a number of permits or allowances that could be purchased at pre specified prices at quarterly sale events. The goal of the APCR is to provide some certainty about the maximum cost that regulated entities would have to pay for allowances they may need for compliance. The California program established a three-tier price structure for the APCR, allocating a number of allowances at $40, $45, and $50. This structure was adopted to give the regulator a better sense of possible imbalances between supply and demand for allowances.

If permit demand exceeds the quantity of permits stored in each of the three containment reserve prices over the full course of 2013 to 2020 compliance (through higher than anticipated economic growth or lower than expected abatement ability), the price could exceed $50 per permit. This could cause higher-than-desired compliance costs for the different carbon-emitting industries. Two solutions exist to these problems: allowing additional permits and across time permit reallocation.

Additional Permits

Borenstein et al. (2014) recommend one of two ways to prevent exhaustion of the containment reserve. The simplest would be to allow firms to purchase unlimited carbon permits from other cap and trade systems at the set reserve price ceiling if the containment reserve is exhausted. These external permits still result in carbon reductions, and with a fixed price ensures compliance costs are capped. The European Emissions Trading Scheme, for example, had an allowance budget of 2,039 million 2013 allowances, or 12.5 times more than California's 162.8 million allowances for 2013. This difference will shrink somewhat upon the entrance of transportation fuels and natural gas into the cap.

The ARB recently included a provision to allow up to 10% of future allowances from the next 3-year compliance phase to be added to the containment reserve. Currently this policy only applies to emissions between 2013 and 2020, however, as there is no formally established cap for post 2020. If legislation extends the cap beyond 2020, and establishes emissions targets for future years, permits from future years can be introduced in present markets at the cost containment price. This allows for greater emissions earlier in the program in exchange for reduced emissions in the future. Eventually, however, there are limits to the feasibility of this approach if future allowable emissions become severely constrained.

Within 2013 to 2020 Cap Permit Trading

Firms are already allowed to save current excess permits for future use. Doing so reduces the chance of future years having substantial price increases with additional permits available for compliance. If there is a shortage of permits early on in the cap, however, the only mechanism in place to limit price increases is early use of the containment reserve. With short-term shocks to permit demand, this policy could produce transitory price spikes, where current-phase permits reach containment reserve prices of over $40/ton while future vintage permit prices remain at the reserve price levels around $12/ton. Large compliance entities may find it profitable to exacerbate this problem by withholding current vintage allowances through deposits into their future compliance accounts. Borenstein et al. (2014) proposes permit "vintage conversion", or letting firms purchase 2018-2020 permits for present use, as an additional means with which to manage price increases. They propose conversion with a fee: thus if the current price exceeds the future price plus a fee, future permits are converted, creating an initial limit on the prices of current prices without starting to exhaust the containment reserve. This policy is not intended to deal with long-run permit price trends. If prices for future vintage permits are as high as prices for current ones, there would be no benefit to conversion.

Market Manipulation and Information

A final means by which the cap can be strengthened is further reductions in the chance for market manipulation. There are means by which large market participants could manipulate their market participation to profit from the cap and trade while raising compliance costs for other firms (Borenstein et al., 2014; Stocking, 2012).

An initial counter against this manipulation proposed by Borenstein et al. (2014) is more clear disclosure of the number of permits held by aggregated sectors or at the anonymous level by firm. In this manner, with greater knowledge of the number of permits specific firms are holding, it would be harder for firms planning market abuse to quietly buy up quantities of permits significantly in excess of expected emissions without alerting other firms that they should themselves purchase more permits to prevent exposure to costly shortages. As other firms acquire permits, the profitability of the plan would decrease and thus discourage attempts at this strategy for market manipulation.

Compliance Cost Certainty: Narrowing the Price Collar

If regulators find that the price of permits fluctuates significantly and that this causes too much uncertainty in compliance costs for firms, an appealing option is to increase the price floor and decrease the cost containment prices so as to further limit the possible range of permit prices. With an extreme narrowing of the price collar, the cap approaches a single known carbon price and is essentially a carbon fee or tax.

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Appendix: Report Recommendations

Recommendation 1: Monitor and assess policy pricing signals and their effect on consumer behavior, and corporate strategies.

While the State of California has put in place an impressive array of programs and policies to reduce carbon emissions from the transportation sector, the report finds that effects of these policies and programs on vehicle and fuel prices, travel costs, and ultimately on emissions reductions are uncertain. These uncertainties are due to complex interactions between technology, consumer/driving behavior, urban development, and other dynamics, which make the estimation of the resulting carbon emissions difficult. Market instruments, such as the cap and trade program, inject a price signal that helps align regulations with demand and induce more efficient attainment of goals.

But additional market mechanisms are needed that create price signals that are more stable, transparent, easy to administer, and effective at influencing vehicle, fuel, and mobility choices. These mechanisms might be fuel taxes linked to the carbon intensity of the fuels, pricing the carbon emissions of housing developments, roadway pricing that favors low-carbon travel, and feebates that increase the price of gas guzzlers and reduce the price of low-carbon electric vehicles.

Recommendation 2: Pursue mechanisms that ensure the implementation of Sustainable Communities Strategies and help attain emissions targets

Cities, counties and MPOs will be more motivated and more effective in achieving the GHG reduction targets in the SB 375 SCS plans if resources, financial and otherwise, were provided. At present, there are essentially no penalties for missing GHG targets and only minimal rewards for achieving them. The allocation of resources to cities and counties should be based on cost-effective reduction of GHG emissions, magnitude of societal co-benefits, and distributional considerations. Recipient jurisdictions should be made accountable for achieving the agreed-upon reductions in GHG emissions.

Recommendation 3: Design durable policy frameworks

The transformation of fuels, vehicles, mobility and infrastructure will take decades. While policies aimed at near-term reductions are desirable, the goal must be long term reductions—for two reasons. First, the principal goal is to place California on a trajectory to achieve large continuing reductions, with a focus on durable policy frameworks that stimulate technological and institutional innovations. Second, the principal benefits, for now, are California's leadership in inspiring others and adopting policies that can be imitated elsewhere (and integrated with other states and nations. Policy designs and institutional commitments should consequently be developed that are robust, durable, and easily integrated and imitated.

Policy certainty and sustainable sources of funding are critical to support the innovation cycle, from research and development to consumer adoption. The state should develop long-term funding mechanisms that reduce uncertainty for the private sector and consumers, so that they can invest and plan with greater confidence. Funding mechanisms should be constructed in conjunction with carbon pricing programs.

Economic efficiency and distributional fairness are also important to ensure the political and economic durability of policies. More research is needed in this area. One example is the refinement of the structure of financial incentives for zero emission vehicles, so these incentives make the most efficient use of public funds, increase their progressiveness, and are most efficient at inducing consumer adoption.

Recommendation 4: Harmonize policies across states

The State harmonized its vehicle performance standards (formerly known as Pavley standards) with the rest of the country in 2012 when it joined the U.S. Environmental Protection Agency and the National Highway Traffic Safety Administration to create a 50-state regulatory program. California is also pursuing regulatory harmonization across seven partner states signatories of a memorandum of understanding on zero emission vehicles, and is seeking to harmonize with Oregon, Washington, and others with low carbon fuel and carbon cap and trade rules. This commitment to harmonization is critical to reduce implementation burden, facilitate coordination and integration, and create scale economies.