# Comparison of Greenhouse Gas Abatement Costs in California's Transportation Sector

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**Abstract:** *California has demonstrated leadership in the area of greenhouse gas (GHG) regulation through the suite of policies adopted under the legislative authority created by AB 32 (the Global Warming Solutions Act of 2006). Currently, the state appears to be on-track to return to 1990 levels of greenhouse gas emissions by 2020. State leaders are now discussing how to best continue progress post-2020. For example, the Air Resources Board's Scoping Plan discusses a range of interim targets for the 2030 timeframe and Governor Brown's Executive Order B-16-2012 sets a goal of achieving an 80 percent reduction below 1990 levels in the transportation sector by 2050. Our work analyzes GHG abatement opportunities and associated abatement costs in the transportation sector, with a focus on the feasibility and cost of compliance with the Low Carbon Fuel Standard.*

## 1. Introduction

As the single largest contributor to California's greenhouse gases (GHGs), reducing emissions from the transportation sector is critical to meeting the state's climate goals. In this analysis, we evaluate the GHG abatement opportunities of cleaner fuels like electricity and natural gas to help transform the transportation sector. A framework for evaluating the cost-effectiveness of abatement measures across all sectors is presented and applied to California's Low Carbon Fuel Standard in the 2020 timeframe. The results of the analysis are designed to inform policymakers and stakeholders addressing GHG emissions reduction from transportation to reach the state's near and long-term targets.

## 2. Background on Transportation Policy in California

The Global Warming Solutions Act, or AB 32, directs the California Air Resources Board (ARB) to develop a set of measures to reduce statewide GHG emissions to 1990 levels by 2020. ARB's 2008 Scoping Plan lays out the framework for reaching AB 32's 2020 target through a suite of measures that cover each sector of California's economy. In addition to AB 32, Executive Order S-3-05 calls for an 80 percent reduction in statewide GHG emissions from 1990 levels by 2050[1], and Executive Order B-16-2012 sets an 80 percent reduction target by 2050 for the transportation sector.[2] The recently adopted update to the Scoping Plan discusses post-2020 climate policy and raises the development of a mid-term statewide GHG target, as well as sector-specific targets to guide the pathway to 2050.[3] As the single largest emitting sector in the state, the transportation sector is the focus of a variety of AB 32 measures. Under ARB's framework, transportation GHG emissions are addressed through programs to promote more efficient and advanced vehicles, reduce the carbon intensity of transportation fuels, and reduce vehicle miles traveled (VMT). In total, transportation measures make up around 30 percent of AB 32's overall reduction target.

### 2.1. Advanced Clean Cars

The Advanced Clean Cars program consolidates and advances existing requirements for criteria pollutants, GHG emissions and requirements for manufacturers to offer a minimum number of ZEVs –

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including plug-in electric vehicles and hydrogen fuel cell vehicles. The Advanced Clean Cars package contains several regulations, including the Pavley II standards, the Zero Emission Vehicle Program, and the Clean Fuels Outlet. Together these regulations will result in improved fuel economy and reduced tailpipe emissions of vehicles on the road.

### 2.1.1. **Pavley Standards**

The Pavley Standards refer to performance measures that establish declining GHG emission standards for cars and trucks out to model year (MY) 2025. Pavley I standards apply to new passenger vehicles and light-duty trucks beginning with MY2009 and are phased-in through MY2016. Pavley I was the first law in the nation to limit GHG emissions from vehicles and will result in 30 percent lower emissions from new cars and trucks by 2016.[4] Pavley I standards had already been approved when the initial Scoping Plan was released but were not being implemented.[5]

Pavley II was adopted under the Advanced Clean Cars package in 2012 and applies to MY 2017-2025. Shortly after Pavley II was passed, the U.S. EPA issued equivalent national light duty GHG and fuel economy standards and Pavley II became subsidiary to the federal rule.

### 2.1.2. **The Zero Emission Vehicle Program**

Also under the Advanced Clean Car package, the ZEV Program calls for manufacturers to offer an increasing number of cleaner vehicles for sale in California. First adopted in 1990, the ZEV Program initially focused on reducing criteria pollutant emissions from vehicles. Throughout the years the program has undergone several changes, and with the passage of AB 32, ARB reviewed and redesigned the ZEV Program with an emphasis on its contribution to GHG reductions.[6] Following the review, the ZEV Program became part of the Advanced Clean Cars package to promote vehicle technology improvements that reduce tailpipe emissions.

The ZEV Program requires that by MY 2018, 4.5 percent of a manufacturer's new sales will be mixture of ZEVs and so-called transitional zero emission vehicles (TZEVs), increasing to roughly 15 percent by MY 2025. In addition to the ZEV Program, Governor Brown issued an Executive Order in March 2012 that sets a target of reaching 1.5 million ZEVs on California's roads by 2025, with interim goals in 2015 and 2020.[2]

## 2.2. **Fuels**

In addition to improving vehicle technology and efficiency, another strategy for reducing GHG emissions in the transportation sector is to address the carbon embedded in fuels, also referred to as the carbon intensity. With petroleum-based fuels supplying 96 percent of transportation demand, ARB determined to design a measure that would lower GHG emissions, diversify the fuel mix in California and support the development of a market for cleaner transportation fuels.[7]

### 2.2.1. **Low Carbon Fuel Standard**

The Low Carbon Fuel Standard (LCFS) regulation calls for a 10 percent reduction in the carbon-intensity (CI) of transportation fuels by 2020. LCFS establishes annual CI targets and sets up a system of credits and deficits based on the targets. The annual compliance targets are set as a percentage reduction of the full lifecycle CI to include the upstream emissions associated with production and extraction. Fuels that are cleaner or have lower lifecycle CIs than the target generate credits for the provider, and fuels that are dirtier or have higher CIs than the compliance target generate deficits. The overall credit balance for fuel providers must meet the annual compliance target, and credits can be traded or banked for future use. To date, LCFS credit generation has exceeded deficits, resulting in over-compliance and net banking. However there is a large degree of uncertainty regarding future compliance pathways under the LCFS.

#### 2.2.2. RFS2

Federally, the Renewable Fuels Standard (RFS2) mandates a minimum volume of biofuels is used in the national transportation fuel supply each year. The volumes started at a total of 9 billion gallons per year in 2008 and rise to 36 billion gallons per year in 2022. The biofuel requirement is subdivided into four separate but nested categories, including: total renewable fuels, advanced biofuels, biomass-based diesel, cellulosic biofuels. Compliance with the RFS2 is met through Renewable Identification Numbers (RINs), which are generated when a biofuel is produced and are detached from the fuel when it is sold to a blender. RINs can be traded to other blenders or banked for future use. Fuels that comply with the RFS2 also can be used towards compliance with the LCFS, earning both RINs and credits. However, the RFS2 does not have a geographical component to the volumetric requirements of the regulation. In other words, it does not require that a proportional share of biofuels be blended into California's fuel supply. As a result, the interactions between the LCFS and the RFS2 are dependent on a variety of factors such as the relative prices and availability of alternative fuels.

### 2.3. Reducing VMT

The final aspect of the state's strategy to reduce transportation emissions is to encourage regional planning that results in lower overall VMT in California. Through access to public transit and improved land use planning, avoided miles help contribute to lower GHG emissions in the state.

#### 2.3.1. Sustainable Communities (SB 375)

SB 375 was passed in 2008 and is included in the original Scoping Plan as a long-term mitigation measure for transportation emissions. The law called for ARB to assign each of California's 18 federally designated metropolitan planning organizations (MPOs) with GHG reduction targets by September 2010. Each MPO is required to submit to ARB a sustainable communities strategy (SCS) that incorporates land use and policies to reduce driving and meet their GHG reduction target. Currently, seven MPOs have adopted strategies and ARB is in the process of evaluating the need to update the MPOs GHG targets.[8]

## 3. Framework for GHG Abatement and Cost Analysis

To evaluate the opportunities for GHG reduction from the transportation sector, we determine the cost and potential of different abatement measures. Our approach is to determine the likely range of emission reduction outcomes and the associated costs of implementing each measure. This dollar per tonne abatement cost, referred to as the Carbon Metric, is a simple metric for evaluating the cost-effectiveness of different abatement options. This can be standardized and applied to all AB 32 policies aimed at reducing California's GHG emissions.

Equation 1 shows the greenhouse gas abatement cost, or the Carbon Metric equation.

**Equation 1**

$$\left(\frac{\quad}{\quad}\right) \quad \frac{\quad}{\quad}$$

Costs and benefits are calculated from a California Total Resource Cost perspective, and do not include interstate transactions. The metric therefore represents the overall statewide cost-effectiveness of a measure, which may result in real costs to some entities and real savings to other entities. Table 1 lists the costs and benefits included in the analysis.

Table 1. Included and Excluded Costs in the CA Total Resource Perspective for Transportation Measures

| Fuel pathway | Included Costs / Benefits | Excluded Costs / Benefits |
|---|---|---|
| Gasoline | Rack price of CARBOB[IV] | Fuel taxes and fees |
| Diesel | Rack price of ULSD[V] | Fuel taxes and fees |
| Ethanol, E10 (10% by volume) | Rack price of ethanol | Fuel taxes and fees |
| Ethanol, E85 (85% by volume) | Rack price of ethanol<br>E85 retail infrastructure | Fuel taxes and fees |
| Biodiesel, B5 (5% by volume) | Rack price of biodiesel<br>Biodiesel storage terminals<br>Fuel tax incentive (only in 2013) | Fuel taxes and fees<br>Fuel tax incentive, post-2013 |
| Biodiesel, B20 (20% by volume) | Rack price of biodiesel<br>Biodiesel storage terminals<br>B20 retail infrastructure | Fuel taxes and fees<br>Fuel tax credit, post-2013 |
| Renewable diesel | Rack price of renewable diesel | Fuel taxes and fees |
| Plug-in electric vehicles | Vehicle price<br>Federal vehicle tax credit<br>Avoided cost of electricity production | California vehicle rebate<br>Retail price of electricity<br>Transmission & Distribution reinforcement costs |
| Hydrogen fuel cell vehicles | Vehicle price<br>Cost of hydrogen production | Fueling stations tax credits, post-2014 |
| Natural gas (inc. CNG, LNG, biomethane) | Vehicle price<br>Citygate price<br>Fuel excise tax credit (only in 2013)<br>C/LNG Refueling infrastructure | Fueling stations tax credits, post-2013<br>Fuel excise tax credit, post-2013 |

Note: We assume that the rack price of fuels such as ethanol and biodiesel reflect the production costs of these fuels – including factors such as feedstock costs, transportation costs, and biofuel production costs.

[IV] California Reformulated Blendstock for Oxygenate Blending. California is what is referred to as a reformulated gasoline market. Reformulated gasoline consists of CARBOB and an oxygenator. The oxygenator is ethanol.
[V] Ultra Low Sulfur Diesel.

### 3.1. Societal benefits

While not included in this analysis, AB 32 requires the consideration of societal benefits and costs.[9] Many alternative transportation fuels with lower GHG emissions provide significant co-benefits, including avoided health costs due to lower criteria pollutants, increased fuel diversity and energy security. While outside the scope of this analysis, we recognize their significance and propose these benefits and costs be considered in a secondary societal cost screen of abatement measures.

## 4. Methodology

### 4.1. Model Overview

The analysis was performed by ICF and focuses on the costs and feasibility of compliance with the LCFS regulation out to 2020. ICF developed an optimization model to determine the lowest cost and lowest emitting solution to meet LCFS compliance. The model incorporates the supply curves of a variety of compliance strategies. The costs of alternative fuels are measured relative to gasoline or diesel, depending on which fuel the measure avoids.

The LCFS system of credits and deficits is used to model compliance whereby any fuel with a carbon intensity above the target for that year generates deficits and any fuel with a carbon intensity below the target for that particular year generates credits. To accurately demonstrate compliance behavior, the model incorporates flexibility mechanisms in the LCFS program such as credit banking and trading between entities. These options promote over-compliance in the early years of the program when the targets are less stringent and credits are potentially less costly.

Compliance with existing regulations under the Advanced Clean Cars package that affect the vehicle fleet and baseline fuel demand are accounted for in the analysis. Fuel economy standards are met through increased penetration of more fuel efficient vehicles. ZEV compliance is assumed to follow ARB's likely compliance scenario which assumes that there are approximately 500,000 ZEVs on the road in 2020.

These factors, as well as increased total VMT due to growth of the vehicle fleet, are used to develop a baseline demand forecast for gasoline and diesel. The model includes the parameters for a variety of feasible compliance strategies, including each pathway's cost, availability and carbon intensity.

### 4.2. Assumptions

#### 4.2.1. Costs

Costs include the incremental fuel, vehicle and infrastructure costs associated with an alternative fuel pathway relative to gasoline or diesel. Two cost scenarios were constructed to cover a range of plausible abatement and cost outcomes. The "Low Cost" scenario uses the low cost estimates for various parameters, while the "High Cost" scenario uses more conservative estimates. Table 2 lists the key parameters that are modified in the plausible low and high cost scenarios. Costs are quantified annually, on a NPV basis from 2011 to 2020 and then reported as dollar per metric tonne abatement costs.

Table 2. Low Cost and High Cost Assumptions (in $2010)

| Fuel / Strategy | Cost Element | Low Cost Case | High Cost Case |
|---|---|---|---|
| Ethanol, E10 Fuel costs [VI] | Corn ethanol, lower CI | +2-4 ¢/gallon | +4-6 ¢/gallon |
| | Sugarcane ethanol | +26 ¢/gallon | +74¢/gallon |
| | Cellulosic ethanol | +50 ¢/gallon decreasing in 2015 | +150 ¢/gallon |
| Ethanol, E85 Refueling Equipment | Retrofits | $125,000 | $150,000 |
| | New stations | $300,000 | $375,000 |
| | Ratio of retrofits to new stations | 40/60 | 20/80 |
| Biodiesel, Fuel Costs [VII] | Soy | -- | -- |
| | Corn oil | +25 ¢/gallon | +50 ¢/gallon |
| | FOGs | +25 ¢/gallon | +50 ¢/gallon |
| Biodiesel, Infrastructure Costs | Refueling infrastructure | $70,000 | $100,000 |
| | New stations | $200,000 | $250,000 |
| | Terminal storage | $120 million | $200 million |
| Renewable Diesel, Fuel Costs [VII] | FOGs | +50 ¢/gallon | +100 ¢/gallon |
| | Cellulosic/waste | +50 ¢/gallon | +100 ¢/gallon |
| Natural Gas, Vehicle Costs | CNG, LNG vehicles | 10 percent reduction by 2020 | No vehicle price reductions |
| PEVs[VIII] eVMT, vehicle costs, infrastructure costs | Electric vehicle miles traveled, PHEVs | +5 percent per year | +3 percent per year |
| | Vehicle costs | 30% reduction by 2020 | 10% reduction by 2020 |
| | Federal tax credit | Available through 2020 | Phased out post-2018 |
| | EVSE costs, L2 residential | $900 | $2,350 |
| | EVSE costs, L2 nonresidential | $2,500 | $7,000 |
| | EVSE costs, DC fast charging | $12,500 | $20,000 |
| Hydrogen FCVs[IX] | Vehicle costs | 25% reduction by 2020 | 10% reduction by 2020 |

[VI] The cost increases for ethanol are relative to average corn ethanol, US.
[VII] The cost increases for biodiesel and renewable diesel are relative to biodiesel produced from soybeans.
[VIII] Plug-in Electric Vehicle; includes both PHEVs and BEVs. Plug-in electric vehicles can be plugged in, whereby the electrical energy is stored in an onboard battery.
[IX] Fuel cell vehicles. Fuel cell vehicles use electricity generated from hydrogen for propulsion and are more efficient than gasoline vehicles.

### 4.2.2. **Emission factors**

The emissions of the fuels are quantified using both well-to-wheel (WTW) and tank-to-wheel (TTW) emission factors. Traditionally, GHG emissions from the transportation sector are evaluated on a WTW basis. However to allow direct comparison with the energy sector measures, TTW emissions are also included. Emissions factors from ARB's LCFS regulation are used to calculate WTW emissions. The one exception is that for electricity, ICF used WTW emissions based on a natural gas-fired combined cycle combustion turbine power plant. TTW emissions represent only the $CO_2$ tailpipe emissions. Hydrogen production plant CO2 emissions for hydrogen and natural gas combined cycle CO2 emissions for electricity are included in the TTW estimates for consistency with analyses of other energy sector program measures. The emissions factors used are shown in Table 3 below.

Table 3. Sample GHG Emission Factors Used in Modeling

| Fuel | WTW g $CO_2e$/MJ | TTW g $CO_2$/MJ |
|---|---|---|
| Gasoline Blendstock, CARBOB | 99.18 | 72.90 |
| Ultra Low Sulfur Diesel | 98.03 | 74.10 |
| Ethanol, US Corn | 86.46 | 0.00 |
| Ethanol, CA Corn Ethanol [a] | 80.70 | 0.00 |
| Ethanol, Brazil Sugarcane [b] | 68.84 | 0.00 |
| Ethanol, Cellulosic | 29.00 | 0.00 |
| Biodiesel, Soybeans | 83.25 | 0.00 |
| Biodiesel, FOGs | 15.04 | 0.00 |
| Biodiesel, Corn Oil | 4.00 | 0.00 |
| Renewable Diesel, FOGs | 29.49 | 0.00 |
| Renewable Diesel, cellulosic | 37.20 | 0.00 |
| CNG | 68.00 | 55.70 |
| Electricity [c,d] | 41.30 | 31.90 |
| Hydrogen (central plant, NG) [e] | 57.80 | 32.00 |

[a] Declining through 2020 to 72 g/MJ; [b] Declining through 2020 to 64 g/MJ; [c] WTW from CEC AB1007 WTT report, TTW from E3; [d] After EER of 3.4 applied; [e] TTW from GREET model, after EER of 2.5 applied.

### 4.2.3. **Financial Assumptions**

Vehicle and infrastructure costs are annualized based on a variety of parameters, including the lifetime of the vehicle and/or infrastructure. To bundle the costs into the Carbon Metric accounting, the costs are annualized. However, many of the costs for various abatement strategies include investments that would extend beyond the analysis period of 2011-2020. For instance, a natural gas vehicle deployed in 2020 would require access to infrastructure based on the calculated fuel consumption of that vehicle over its lifetime. The abatement costs capture the annualized fraction of costs that the particular vehicle will require over its lifetime. The costs are built up dynamically, however, to ensure that infrastructure is utilized up to a particular capacity before including additional costs in the Carbon Metric.

For vehicles, we assumed a life of 10-12 years, depending on the vehicle class and likely application. Furthermore, we made assumptions regarding fuel consumption, vehicle sales, vehicle turnover rates, annual mileage and fuel economy values based on our analysis of data from ARB's EMissions FACtors model from 2011 (EMFAC2011).[10] All infrastructure costs were amortized assuming a 20 year life. All costs are represented in real 2010 dollars. Annual inflation was assumed to be 2 percent. The real discount rate, 5.66 percent, is applied to all flows: capital costs, avoided costs, and avoided emissions.

### 4.3. LCFS Re-adoption

Since the analysis of the Low Carbon Fuel Standard was completed, the ARB has outlined several changes to the program that will impact the results. Some of the changes were originally proposed as amendments to the regulation; however, other changes that affect the results are in response to legal challenges regarding ARB's authority to implement the LCFS.[11] In part because of the legal challenges, ARB is likely to re-adopt the entire LCFS regulation wholesale with changes, rather than make changes through amendments. The following are the most critical issues that will impact the results of this analysis:

- As a result of the legal challenges, ARB is required to conduct an environmental review of the program; and while ARB continues to enforce the regulation, the carbon intensity reduction requirements are being frozen at 2013 levels through 2015 (i.e., 1 percent carbon intensity reductions). This means that there is increased opportunity for banking credits in 2014 and 2015 because there are fewer deficits generated by refiners and other regulated parties that distribute gasoline and diesel.

- ARB is reviewing the indirect land use change (ILUC) values attributed to liquid biofuels derived from conventional feedstocks, including corn ethanol, sugarcane ethanol, sorghum ethanol, soy oil biodiesel, and canola oil biodiesel. The initial results of ARB's analysis indicate that the carbon intensities of these biofuels may decrease by as much as 50 percent.[12] These changes will have a significant impact on the LCFS program and the results of our analysis because blending liquid biofuels of lower carbon intensity make the largest contribution towards compliance. As the ILUC values decrease, this changes the Carbon Metric calculation because the denominator (GHG reductions) increases with no changes to the numerator (costs). Furthermore, this may have knock-on effects in the market because there will likely be less pressure to purchase credits from gaseous fuels (e.g., CNG) or from advanced vehicle solutions (e.g., plug-in electric vehicles).

- ARB is also increasing available opportunities to generate LCFS credits. For instance, off-road transportation electrification – specifically electric forklifts and fixed guideway applications (e.g., light rail) – will be able to earn LCFS credits. Similarly, refiners will be able to earn credits for GHG reduction measures implemented at refineries. With more credit earning opportunities becoming eligible, many of which will be available at attractive costs, the supply of credits will likely go up, thereby putting downward pressure on credit prices and the overall costs of the program.

- ARB is also considering a cost-containment mechanism for the LCFS program. At this point, we do not think that this mechanism will have a significant impact on our modeling results, but will limit the price paid for LCFS credits. However, because of differences between how credits are earned and how the Carbon Metric calculations are performed (on a total resource cost basis, rather than on a regulated party basis), it is unlikely that this will have a material impact on the results of our analysis using an optimization model.

Although ARB has maintained that the target 10 percent reduction in carbon intensity for 2020 will remain unchanged, the opportunity to bank additional credits, reductions in the carbon intensity of liquid biofuels from conventional feedstocks as a result in changes to ILUC estimates, and the increased credit-generating opportunities in the LCFS market will likely decrease the costs of the program. Furthermore, these changes may change the compliance outlook in the high-cost scenario.

## 5. Results of Phase I: 2020

The results of the model give insight into the feasibility and costs of LCFS compliance under two cost scenarios. Under both scenarios a broad range of compliance strategies are deployed. For Phase I of this analysis compliance is defined as a net zero balance of credits in 2020. The results indicate that under the current regulation post-2020 compliance will be challenging, however the proposed changes to the program design will impact both the availability of abatement opportunities and costs of compliance. Post-2020 abatement is explored in Phase 2 of the analysis.

The abatement costs are shown in five phases, corresponding to the changes in the carbon intensity targets and reflecting the availability of low carbon fuels over this time period Both the low and high cost scenarios rely on over-compliance in the early years of the program when the intensity targets are less stringent. Even though the unit abatement costs of strategies deployed are higher, the average unit abatement cost for the later Phases decrease due to the banking activity in the years 2011-2016. It is important to note there is considerable uncertainty in forecasting the availability and cost of biofuels out to 2020. In the high cost scenario, abatement falls short of meeting LCFS compliance.by about 1 MMT. However the changes to the regulation will increase the supply of credits and influence the feasibility and costs of compliance. Given the modifications and uncertainty surrounding several key assumptions, the results are therefore illustrative of potential compliance pathways given the data that is currently available.

Table 4. Unit Abatement Costs and Marginal Abatement in 2020

| Scenario | GHG Reductions (MT) | Avg Abatement Cost ($/tonne) | Abatement Cost of Last Increment ($/tonne) |
|---|---|---|---|
| Low Cost | 16.27 | $94 | $75 |
| High Cost | 14.94 | $182 | $219 |

Table 5. LCFS Compliance Targets in Phases

| LCFS Phase | Carbon Intensity Reduction Target | Corresponding Years |
|---|---|---|
| Phase 1 | 0–1.0 percent | 2011-2013 |
| Phase 2[13] | 1.0–2.5 percent | 2013-2015 |
| Phase 3 | 2.5–5.0 percent | 2015-2017 |
| Phase 4 | 5.0–8.0 percent | 2017-2019 |
| Phase 5 | 8.0–10.0 percent | 2019-2020 |

Table 6. Abatement Curve for Plausible Low Cost Scenario

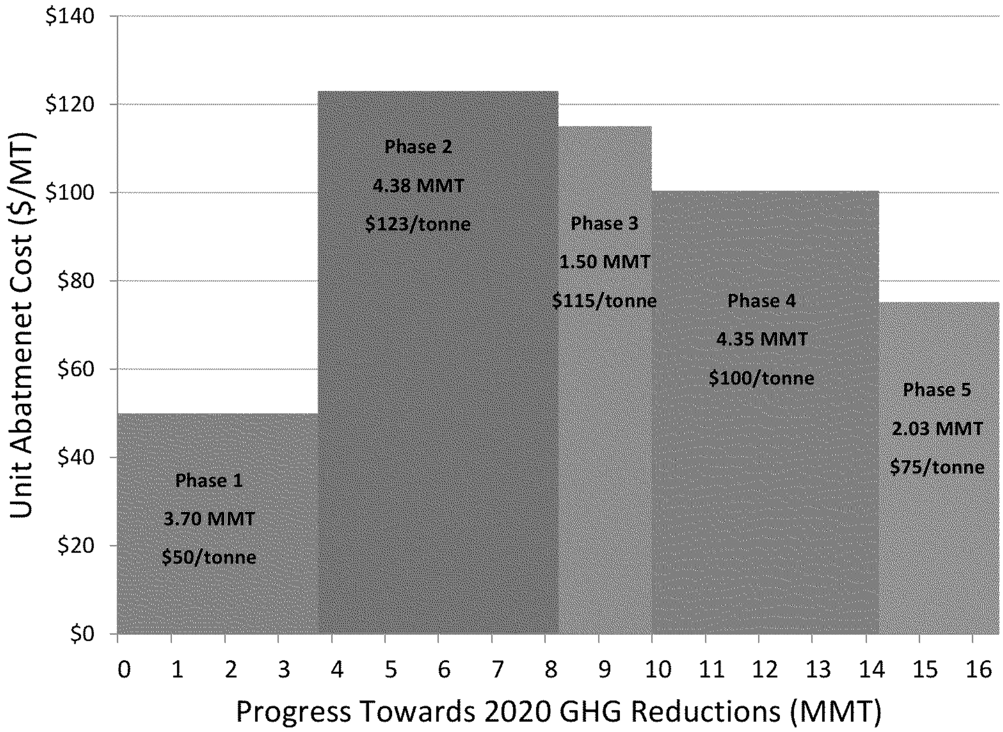
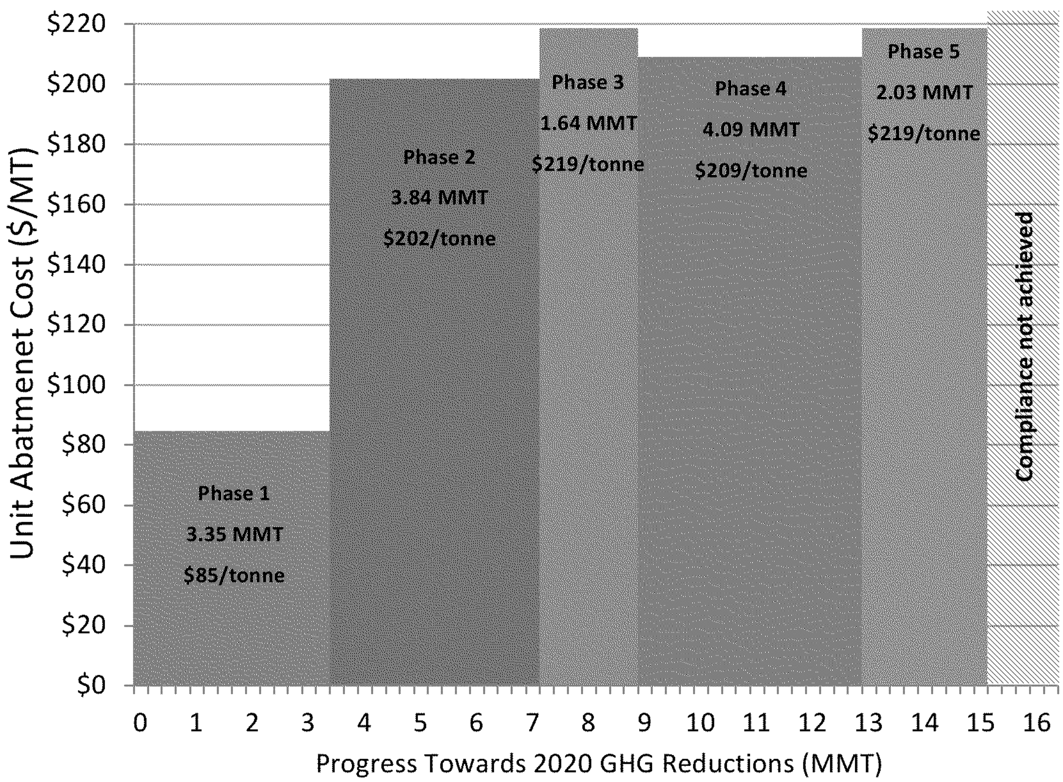



Table 7. Abatement Curve for Plausible High Cost Scenario



Note: Compliance is not achieved in the Plausible High Cost Scenario

Table 8. Average Abatement Costs for Plausible Low and Plausible High Cost Scenarios

| Phases | Plausible Low Cost | | | | Plausible High Cost | | | |
|---|---|---|---|---|---|---|---|---|
| | Reductions (in MMT $CO_2e$) | | Costs (in $/MT) | | Reductions (in MMT $CO_2e$) | | Costs (in $/MT) | |
| | WTW | TTW | WTW | TTW | WTW | TTW | WTW | TTW |
| Phase 1 2011-2013 | 3.74 | 10.09 | $50 | $8 | 3.35 | 8.57 | $85 | $10 |
| Phase 2 2013-2015 | 8.13 | 12.25 | $123 | $70 | 7.19 | 9.91 | $202 | $25 |
| Phase 3 2015-2017 | 9.85 | 12.88 | $115 | $40 | 8.83 | 11.99 | $219 | $69 |
| Phase 4 2017-2019 | 14.22 | 16.09 | $100 | $33 | 12.91 | 12.61 | $209 | $110 |
| Phase 5 2019-2020 | 16.27 | 17.64 | $75 | $70 | 14.94 | 14.91 | $219 | $157 |
| **Average Unit Abatement Cost** | | | **$94** | **$39** | | | **$182** | **$79** |

## 6. Discussion and Conclusions

This section outlines the most significant takeaways from the 2020 modeling exercise. Most notably, under both the plausible low and high cost scenarios, achieving the LCFS requirements in 2020 depends on over-compliance in the earlier years of the program. The model also suggests GHG reductions from the diesel pool can help cover deficits in the gasoline pool.

The fuels that are expected to make the most significant contributions to compliance in the short term are Brazilian sugarcane ethanol and biodiesel from corn oil. Cellulosic biofuels could play an important role but rapid expansion of availability, production and capacity is needed. The role of high-level blends of ethanol depends on the availability of supply of low carbon biofuel for the E10 market Natural gas will also play an important role in compliance. Across both scenarios, CNG and LNG in the medium- and heavy-duty sectors account for about 11-12 percent of LCFS credits generated. Electricity and hydrogen contribute between nine to ten percent contribution towards LCFS compliance, driven by compliance with the ZEV Program. The modeling exercise captures most of the dynamics in a diversified transportation fuel market that we would expect – as the costs of abatement increase to meet compliance, the scope of strategies to achieve compliance in the transport sector broadens.

As discussed in Section 4.3, it is important to note the upcoming re-adoption of the LCFS and package of changes to the regulation will impact the costs and availability of credits. This analysis was performed prior to these changes and the results are meant to be illustrative of the framework for evaluating GHG abatement opportunities. Reported abatement costs are not a prediction of credit prices or program costs.

Our next phase of work will apply this framework to evaluate the emissions reduction opportunities in the transportation sector in the 2030 timeframe. Future analysis will account for transportation sector abatement beyond carbon intensity reductions, including more aggressive vehicle efficiency measures and VMT reduction measures. We intend to integrate transportation with other sectors in order to capture the interactive effects between certain measures and the trade-offs between abatement actions across the entire economy. The results will illustrate both the reduction potential and costs associated with a variety of GHG reducing pathways to help inform the optimal mix of policies to meet longer term reduction goals. Given the relative contribution of the transportation sector to California's emissions and the transition towards cleaner power in the state, we believe electricity is a promising low-carbon alternative to conventional transportation fuels in the long term. As California's electricity grid becomes even cleaner, PEVs and other forms of transport electrification is likely to be a fundamental driver towards meeting the state's climate goals.

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[1] Office of California Governor Edmund G. Brown , Executive Order S-3-05, Available online: http://gov.ca.gov/news.php?id=1861

[2] Office of California Governor Edmund G. Brown , Executive Order B-16-2012, Available online: http://gov.ca.gov/news.php?id=17472

[3] Air Resource Board, First Update to the Climate Change Scoping Plan: Building on the Framework. Adopted May, 2014, Available online: http://www.arb.ca.gov/cc/scopingplan/2013_update/first_update_climate_change_scoping_plan.pdf

[4] AB1493 directed ARB to set the standards which applied to new vehicles starting in the 2009 model year. Available online: http://www.leginfo.ca.gov/pub/01-02/bill/asm/ab_1451-1500/ab_1493_bill_20020722_chaptered.pdf

[5] At the time, implementation of Pavley I was pending a legal challenge to EPA for a waiver necessary under the Clean Air Act to implement vehicle tailpipe emission standards.

[6] Air Resources Board, Zero Emission Vehicle (ZEV) Program, Available online: http://www.arb.ca.gov/msprog/zevprog/2011zevreg/2011zevreg.htm

[7] Air Resources Board, The Role of a Low Carbon Fuel Standard in Reducing Greenhouse Gas Emissions and Protecting Our Economy, Available online: http://www.arb.ca.gov/fuels/lcfs/lcfs_wp.pdf

[8] ARB First Update to the Climate Change Scoping Plan, Available online: http://www.arb.ca.gov/cc/scopingplan/2013_update/first_update_climate_change_scoping_plan.pdf

[9] § 38562(6) and § 38561(d) of the CA Health and Safety Code

[10] Air Resources Board, Mobile Source Emissions Inventory, Current Methods and Data, EMFAC2011, Available online: http://www.arb.ca.gov/msei/modeling.htm

[11] The LCFS has been challenged and upheld under both federal and state court cases, however on July 15, 2013, the State of California Court of Appeals ruled that ARB must address the California Environmental Quality Act and Administrative Procedure Act issues associated with the original adoption of the regulation. ARB staff had planned to propose amendments to the Board in October 2013 and again in 2014, but in light of the ruling, decided to consolidate amendments and return to the Board in 2014 for re-adoption.

[12] ARB, iLUC Analysis for the Low Carbon Fuel Standard (Update), March 11 Workshop, Available online: http://www.arb.ca.gov/fuels/lcfs/lcfs_meetings/iluc_presentation_031014.pdf

[13] Proposed regulation changes maintain a 1 percent reduction target 2013-2015. Discussed in ARB's LCFS re-adoption concept paper. Available online: http://www.arb.ca.gov/fuels/lcfs/lcfs_meetings/030714lcfsconceptpaper.pdf