



Final

Post-2020 Carbon Constraints

Modeling LCFS and Cap-and-Trade

February 2017

Submitted to:
California Electric Transportation Coalition
California Natural Gas Vehicle Coalition
Ceres
Coalition for Renewable Natural Gas
Environmental Entrepreneurs
National Biodiesel Board

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Executive Summary

Transportation accounts for 37 percent of California’s greenhouse gas (GHG) emissions and for 50 percent when refinery emissions are added;¹ and its share of emissions is expected to grow in the future because other sectors (e.g., electricity generation) are reducing GHG emissions at a much faster rate. Recent legislation (SB 32, Pavley) requires California to reduce emissions by 40 percent below 1990 levels. In this report, ICF has assumed that this goal would be achieved through some combination of policies and programs similar to those in place today, i.e., cap-and-trade and the Low Carbon Fuel Standard (LCFS) programs. The objective of this report is to quantify the cost and emission impacts of the LCFS as a complementary mechanism to a cap-and-trade program, both of which are assumed to be extended to 2030.

ICF’s approach to the analysis was rooted in a fundamental understanding of the costs of abating GHG emissions, and the amount of GHG emissions that can be reduced at a given cost. The relationship between cost and abatement is referred to as the *marginal abatement cost curve*. In principle, the marginal abatement cost curve helps us understand the *allowance price* in the cap-and-trade market, and is a proxy for compliance costs in the market. As the cap reduces over time, which changes depending on the reductions expected from complementary measures like the LCFS program, the allowance price will change (presumably increasing) to reflect the shape of the marginal abatement cost curve. When the curve is steep, allowance prices will increase more rapidly and are subject to volatility. When the curve is flatter, allowance prices are subject to more modest increases and tend to be more stable. Our analysis, then, focused on a) the amount of GHG reductions delivered via the LCFS program as a complementary measure, which takes pressure off the cap in the cap-and-trade program and b) the associated impact on allowance pricing and compliance costs.

ICF used a combination of internal LCFS compliance modeling (using an optimization framework, whereby a lowest-cost, lowest-emissions solution is determined based on supply-demand curves in the transportation sector) and the IPM Plus® model. ICF developed compliance pathways to lower GHG emissions 40 percent below 1990 levels by 2030 under a range of emissions scenarios. The base model, IPM® provides a detailed representation of the US electric power sector, and is widely used by a range of private and public sector clients, in addition to being the platform used by EPA to support their analysis of the Clean Power Plan as well as other major air regulations under the Clean Air Act.²

ICF considered four scenarios for LCFS program compliance with different carbon intensity targets in 2030: 10%, 15%, 20%, and 25%. ICF notes that the stakeholder group requested that ICF model a 25% carbon intensity target for the LCFS program; this should not be viewed as a feasibility analysis of the target. For each scenario, ICF considered a mix of alternative fuels and advanced vehicle technologies that would be required to achieve compliance by 2030. This compliance scenario was linked to the IPM

¹ California GHG Emissions Inventory, 2016 Edition, California Air Resources Board. Available online at <https://www.arb.ca.gov/cc/inventory/data/data.htm>.

² EPA Power Sector Modeling, available online at www.epa.gov/airmarkets/power-sector-modeling.

Plus® model to estimate the corresponding allowance price impacts of different transportation emission trajectories.

ICF modeling results indicate the following key conclusions:

- ICF’s analytical findings support the argument that the LCFS program reduces the emissions required under the GHG allowance cap, thereby lowering the allowance price and flattening the marginal abatement cost curve. ICF finds that the marginal abatement cost curve, which is used to estimate the market clearing price for allowances, is quite steep in 2030. As a result, we find that a reduction of 3—14 MMT in transportation emissions in 2030 yields a reduced allowance price spread of \$5—29/ton by 2030.
- The LCFS does not substantially raise overall GHG compliance costs in the transportation sector, especially in the short- to medium-term future. The moderately stringent LCFS programs considered in this report (i.e., a 15-20% carbon intensity target) deliver ongoing long-term abatement that we do not observe in a scenario with cap-and-trade on its own. Consequently there are long-term benefits once the initial (and potentially high cost) barriers are overcome in the transportation sector.
- Because refiners are the regulated entity that will face the burden of compliance costs, ICF finds it useful to also frame the compliance costs on a per barrel basis. In this case, the more stringent LCFS programs yield a slightly higher (about 10%) overall cost; however, these scenarios also yield considerably higher petroleum reduction via fuel diversification, which has its own benefits (although not quantified in this report).
- ICF estimates that the scenarios with more stringent LCFS targets (i.e., 15%, 20%, and 25% carbon intensity targets) will reduce petroleum consumption by 18—26% when compared to the current 10% target. This is an important finding when coupled with the finding that there are substantially similar compliance costs, especially with a 15—20% carbon intensity target. This means that the LCFS program can help ease compliance in the cap-and-trade program, while also making significant contributions to petroleum reduction.
- ICF also finds that the design of the LCFS program post-2020 is especially critical: If the stringency of the LCFS program is increased too rapidly in the first 2-3 years after 2020, then we find that this could lead to the program having insufficient credits to offset deficits.

Introduction

Transportation accounts for 37 percent of California’s greenhouse gas (GHG) emissions and for 50 percent when refinery emissions are added;³ and its share of emissions is expected to grow in the future because other sectors (e.g., electricity generation) are reducing GHG emissions at a much faster rate. California has existing commitments that reflect the three broad approaches to reducing transportation emissions: improve vehicle efficiency; deploy alternative fuels and vehicles; and reduce miles traveled. The simplicity of this narrative belies the complexity of the transportation sector, as it is generally recognized as one of the most complicated sectors with regards to GHG abatement due to challenges such as the market dominance of fossil fuels, changing consumer behavior, implementation of land use plans, and commercialization of low-carbon fuels.

Overview of California’s Transportation Policy Landscape

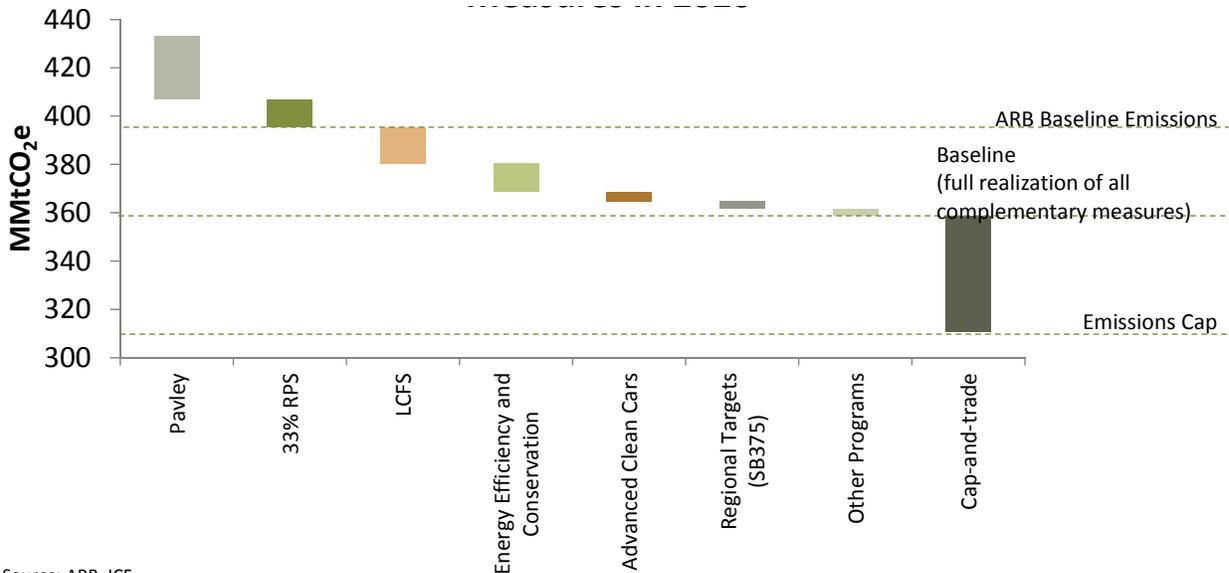
In California, carbon emissions are constrained through 2020 based on a combination of the Cap-and-Trade program and complementary measures (see figure below), which include tailpipe GHG standards, the Low Carbon Fuel Standard (LCFS) program, and Sustainable Communities Strategies (SCS, per SB 375).⁴ Complementary measures are designed to reduce demand for carbon allowances and lower prices, and vice versa.⁵

³ California GHG Emissions Inventory, 2016 Edition, California Air Resources Board. Available online at <https://www.arb.ca.gov/cc/inventory/data/data.htm>.

⁴ ICF notes that this report focused on the impacts of LCFS on the Cap-and-Trade program. This report does not examine other complementary programs used for commercialization of low carbon fuels or advanced vehicle technologies.

⁵ Note that Pavley refers to tailpipe GHG standards for light-duty vehicles through MY 2025.

Figure 1. Projected Emission Reductions from Complementary Measures in 2020⁶



Source: ARB, ICF

Cap-and-Trade Program. Under the Cap-and-Trade Program, CARB sets a limit (cap) on major sources of GHG emissions from capped sectors. The cap declines approximately 3 percent each year beginning in 2013. Regulated parties can trade permits (allowances) to emit GHGs or reduce their GHG emissions. Allowances are auctioned quarterly and these auctions are held by CARB. Parties are also allowed to bank allowances to protect themselves against shortages and price swings in the market. If a regulated party does not meet CARB’s compliance standards, they must provide four allowances for every ton of emissions not covered by the compliance deadline.

Tailpipe GHG standards. Under Clean Air Act authority, California has adopted light-duty vehicle GHG standards that are consistent with federal fuel economy and GHG standards. The most recent passenger vehicle standards, covering cars and light trucks, were promulgated by the National Highway Traffic Safety Administration (NHTSA) and the Environmental Protection Agency (EPA) in 2012 for model years 2017 and beyond. The standards are a combination of fuel economy standards (referred to as Corporate Average Fuel Economy standards or CAFE standards)⁷ established by NHTSA and GHG emission standards from the EPA.⁸ NHTSA and EPA projected that the fleet-wide on-road fuel economy of new passenger vehicles to be in the range of 40 miles per gallon (MPG) in 2025.

LCFS program. California’s LCFS is designed to be a flexible market-based mechanism to reduce GHG emissions of transportation fuels, like reformulated gasoline and diesel, on a lifecycle basis. The LCFS was established in 2007 through a Governor’s Executive Order and requires those who produce petroleum-based transportation fuels to reduce the carbon intensity (CI) of their fuels by 10 percent by

⁶ ICF notes that it is difficult to distinguish absolutely between reductions across various programs, such as the LCFS program, the Zero Emission Vehicle program, and Pavley standards. As such, the values shown should be considered estimates for the reductions achieved for each measure.

⁷ Under the authority of the Energy Policy and Conservation Act (EPCA) and amend by the Energy Independence and Security Act (EISA).

⁸ Under the authority of the Clean Air Act.

2020. The LCFS applies to transportation fuel that is sold, supplied, or offered for sale in California and to any regulated party that produces those transportation fuels, like oil refineries and other distributors. The program is administered by the California Air Resources Board (CARB) and is implemented using a system of credits and deficits. Transportation fuels that have a higher carbon intensity than the compliance standard yield deficits, and fuels that have a lower carbon intensity (such as low carbon ethanol, biodiesel, renewable diesel, fossil and renewable natural gas, or electricity) generate credits. Regulated entities who generate deficits must offset these by purchasing credits.

Sustainable Communities Strategy (SCS). California's Senate Bill 375 (2008) aims to reduce energy use and GHG emissions from the transportation sector by reducing the amount that Californians drive. The goal of SB 375 is to expand transportation choices that reduce the need to drive by focusing on new development in places where residents can travel by foot, bicycle, or transit. In all metropolitan areas with populations over 200,000, metropolitan planning organizations (MPOs) are responsible for preparing a regional transportation plan (RTP) describing how transportation revenues across the region will be spent over the next 25 years. SB 375 requires that MPOs include a SCS that includes a regional land use plan and details how land use changes, in combination with the transportation projects and policies in the RTP, will help the region meet regional GHG reduction targets set by the state.

These programs have multiple complementary aspects. For instance, the cap-and-trade program applies a price signal—information conveyed to both consumers and producers of fuels—consistently to all aspects of the transportation challenge thereby encouraging both short-term and long-term emission reductions from efficiency improvements, lower carbon fuels, and reduced travel. The cap-and-trade program is designed to be flexible and serves as a backstop to ensure that the 2020 target is met. For instance, the cap-and-trade program sends a price signal to dampen the potential rebound effect of consumers increasing their driving in response to lower household transportation costs from having more efficient vehicles.

Overview of Consumer Dynamics

The interactions between the aforementioned programs are non-trivial, especially how they impact industry stakeholders and consumers.

Consider the impacts of these regulations on consumers. For every unit of fuel sold in California, a refiner must surrender carbon allowances in the cap-and-trade market. Similarly, refiners must offset deficits generated in the LCFS market by purchasing LCFS credits. Refiners typically include the cost of cap-and-trade and LCFS as a line item in the bill of lading at the distribution terminal—the point in the distribution chain where transport fuels are transferred from a pipeline or storage facility to tanker trucks to be distributed locally to the retail market. From the distribution terminals, marketers tend to pass along the costs of cap-and-trade in their retail pricing of the fuel. This is difficult to verify, especially as a result of the recent decreases in crude oil prices. However, based on our understanding of today's market, refiners and marketers elect to pass the cost of cap-and-trade and LCFS on to consumers in full.

It is equally important to understand how consumers benefit from these programs. In the case of the cap-and-trade program, proceeds from the state-owned allowance auction are deposited into the

Greenhouse Gas Reduction Fund (GGRF), which was established under AB1532 (Pérez). The legislature and Governor allocate funds from GGRF to projects that help California achieve its GHG reduction goals while realizing additional health, economic, and environmental benefits. The GGRF funds can help make the transition to cleaner transportation more affordable for consumers via low-emissions vehicle rebates and transit-oriented development grants. In the LCFS market, the credits procured by the refiners are not allocated to any government entity but awarded to low-carbon fuel providers—with the value from sale of credits used as an investment in lower carbon fuels.⁹ This is reminiscent of the Renewable Portfolio Standard, whereby market value is transferred to generators of renewable electricity via renewable energy credits (RECs). Similarly, the market-based approach of the LCFS allows capital to be invested more efficiently than if it were allocated by a government entity. For instance, by 2020 we estimate that the purchase of LCFS credits will yield an annual investment of \$1.6-3.2 billion in low carbon fuels.

These programs also yield significant ancillary benefits, including reduced criteria pollutants and energy security benefits. In a previous study,¹⁰ ICF monetized these benefits out to 2020 based on the current structure of the LCFS program (with a 10% carbon intensity target in 2020), and found the cumulative criteria pollutant benefits could be as high as \$359 million by 2020 and the cumulative energy security benefits could be as high as \$1.2 billion by 2020. ICF also found that LCFS could help add as many as 9,100 jobs in California and 31,500 jobs, cumulatively, in the rest of the United States by 2020.

Understanding how consumers respond to price changes. Economists typically gauge price response in terms of the *price elasticity of demand* for transportation fuels i.e., the percentage that the demand for gasoline is likely to decline for each percent increase in the price of fuel. The pure price response to the expected range of carbon allowance prices—say on the order of \$10-50 per ton CO₂—may appear to be quite limited. Over the short-term, the price elasticity of demand for gasoline is generally quite small, on the order of -0.10, which translates to a 1% reduction in gasoline demand for a 10% increase in gasoline prices.¹¹ Short-term elasticity tends to be particularly low because there are few short-term response options beyond reducing the number and length of optional trips, while long-term elasticities can be more significant. While over the short-term, people may only change their vacation plans or inflate their tires, over the longer term, they can alter capital investments decisions such as the purchase of a more fuel-efficient car, change where they choose to live and work, and influence urban development and transit planning.¹² Furthermore, research suggests that if the increase in price is perceived to be more permanent (e.g., such as that resulting from a carbon price), then consumers are much more sensitive to

⁹ ICF notes that LCFS credits are generated by various entities in the supply chain of different fuels. In some cases it goes to the producer, the distributor, the fueling station owner, or the vehicle owner.

¹⁰ ICF, California's Low Carbon Fuel Standard: Compliance Outlook and Economic Impacts, April 2014, available online at <http://www.caletc.com/wp-content/uploads/2014/04/ICF-Report-Final-2.pdf>.

¹¹ Hughes, J.E., C. R. Knittel, and D. Sperling. 2008. Evidence of a Shift in the Short-Run Price Elasticity of Gasoline Demand. *The Energy Journal* 29:1. Available at: http://web.mit.edu/knittel/www/papers/gas_demand_final.pdf

¹² Knittel, C.R. n.d. The Importance of Pricing Transportation Fuels within California's Cap-and-Trade Program. MIT Sloan School of Management. Available at: <http://web.mit.edu/knittel/www/papers/CATransportationFuels.pdf>

price increases than for temporary price fluctuations (e.g. resulting from fluctuations in global oil prices).¹³

California's Post-2020 Transportation Policy Landscape

Recent legislation (SB 32, Pavley) requires ARB to reduce emissions by 40 percent below 1990 levels. For the purposes of this report, we have assumed that this goal would be achieved through some combination of policies and programs similar to those in place today i.e., cap-and-trade and the LCFS programs. For instance, AB 197 (Garcia) simply lays out the ground rules for adopting rules and regulations to achieve the 40 percent reduction, rather than explicitly extending cap-and-trade or the LCFS program. This report focuses on the technical challenges and opportunities associated with achieving a 40 percent reduction below 1990 levels.

Consider, for instance, that cap-and-trade on its own is unlikely to induce demand for lower carbon alternative fuels needed to achieve longer-term GHG reduction targets. Refiners regulated under a cap-and-trade program are price takers. In other words, the costs of reducing GHG emissions in the transportation fuels sector are relatively high, thereby leaving refiners with little motivation to reduce GHG emissions substantially through their own actions. As a result, refiners will simply purchase allowances. And the cost of those allowances are highly likely to be paid by consumers of gasoline and diesel. In addition, this market condition raises the cost of allowances across all sectors as the rest of the economy must pay for an equal amount of reductions from other sectors to make up for the transportation sector shortfalls.

The LCFS program, on the other hand, compels refiners to take action to reduce GHG emissions from transportation fuels. Further, it is designed to provide a long-term price signal to stakeholders in the low carbon fuel economy that is otherwise lacking from a cap-and-trade program, while offering complementary benefits, such as reducing consumers' long-term exposure to fuel price volatility. The LCFS program can send clear policy signals to investors that long-term solutions are needed for lower carbon and cost competitive transportation fuels while yielding modest near-term emission reductions. The LCFS directly encourages innovation and investment in the supply and delivery of cost competitive lower carbon fuels (e.g., biofuels, electricity, natural gas, and hydrogen). This complements the price signal placed on carbon emissions imposed by a cap-and-trade system.

The LCFS program reduces the emissions required under the GHG allowance cap, thereby lowering the allowance price and flattening the marginal abatement cost curve. Furthermore, many LCFS compliance strategies yield cap-and-trade benefits. For example, the increased blending of lower carbon biodiesel and/or renewable diesel with conventional diesel helps achieve the targets of the LCFS program and yields a reduction in the GHG emissions from the production and use of petroleum-based fuels, thereby reducing an entity's obligation under a cap-and-trade program.

¹³ Li, S., J. Linn, and E. Muehlegger. Gasoline Taxes and Consumer Behavior. Working Paper. National Bureau of Economic Research, March 2012. Available at: <http://dash.harvard.edu/bitstream/handle/1/8506866/RWP12-006-Muehlegger.pdf?sequence=1>

Report Objective

The objective of this report is to quantify the cost and emission impacts of the LCFS as a complementary mechanism to a cap-and-trade program, both of which are assumed to be extended to 2030. The following sections outline the methodology employed in the analysis to achieve this objective and our associated findings.

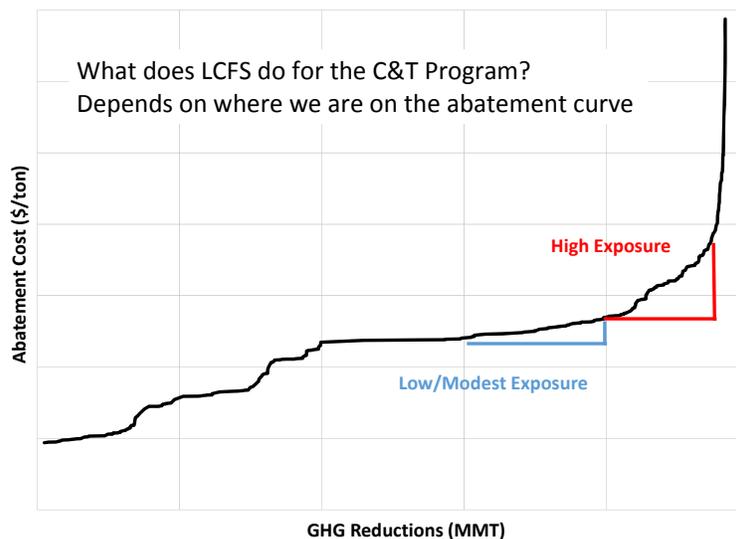
Methodology

ICF’s approach is rooted in a fundamental understanding of the costs of abating GHG emissions, and the amount of GHG emissions that can be reduced at a given cost. The relationship between cost and abatement is referred to as the marginal abatement cost curve (see figure below). The horizontal axis quantifies the cumulative GHG reductions that can be achieved, whereas the vertical axis quantifies the cost at which that reduction can be achieved. Ultimately, the extent to which the LCFS program reduces exposure to higher allowance prices in the cap-and-trade program is directly related to the following:

- What level of GHG reductions is the LCFS program delivering?
- How steep is the marginal abatement cost curve as we approach the 2030 target?

Analysts can certainly disagree over the costs and reductions attributable to various GHG reduction strategies in a carbon-constrained economy; however, most studies to date have shown that there is increased volatility in allowance pricing as greater GHG emissions reductions are required. The figure below illustrate two risk environments for allowance pricing: In the low risk case, the assumption is that there are still a significant number of GHG reductions to be achieved at relatively low prices. However, in the high risk case, seeking greater GHG reductions increases the allowance price significantly and rapidly.

Figure 2. Illustrative Abatement Supply Curve



ICF’s methodology was designed to answer the two questions outlined above. Our team paired an optimization model developed to characterize LCFS compliance under different carbon intensity targets and the IPM Plus® Model. The following sub-sections describe these models and how they were employed in the analysis.

Modeling the LCFS Program

ICF employed an internally developed optimization model that considers a variety of compliance strategies based on the costs of low carbon transportation fuels (relative to gasoline or diesel), and its

corresponding abatement potential. The model dynamically solves for a low-cost, lowest emission solution while considering inter-temporal trading and banking behavior in the LCFS program. ICF modeled compliance using the LCFS program's deficit and credit system i.e., gasoline and diesel consumption yielded deficits and the introduction of lower carbon fuels yielded credits. Any fuel with a carbon intensity above the baseline for that year generated deficits and any fuel with a carbon intensity below the baseline for that particular year generated credits. The model is calibrated for years 2011-2015 based on data reported by CARB and includes the deficit and credit generating pathways outlined in the table below. The demand for gasoline and diesel regulated by the LCFS program was forecasted to 2030 based on ICF's analysis of a variety of sources, including CARB's EMFAC model¹⁴ and Sustainable Freight Strategy,¹⁵ the California Energy Commission's Integrated Energy Policy Report (IEPR) for 2015,¹⁶ and data from the Energy Information Administration. The forecasts include existing regulations, such as tailpipe GHG standards for light-duty and heavy-duty vehicles, anticipated VMT reductions from submitted sustainable community strategies, and the Zero Emission Vehicle Program.

ICF notes that our optimization model is driven by LCFS compliance, and the supply curves for various alternative fuels and technologies that generate credits in the LCFS program. In other words, we do not simply sum the credits that would be generated when each fuel pathway or technology reaches its maximum or some pre-determined potential. The maximum potential for each fuel pathway is likely greater than what our modeling assumes will be deployed. However, the underlying premise of the analysis is that the market will achieve compliance through a lowest-cost pathway, which means that the modeling will not choose to over-comply unless it yields a lower cost in some future year of the program (e.g., through banking of credits).

¹⁴ More information available online at <https://www.arb.ca.gov/msei/categories.htm>.

¹⁵ More information available online at <http://www.casustainablefreight.org/>.

¹⁶ California Energy Commission, 2015 Integrated Energy Policy Report, available online at http://www.energy.ca.gov/2015_energy_policy/.

Table 1. Overview of Fuels Considered in LCFS Compliance Scenarios

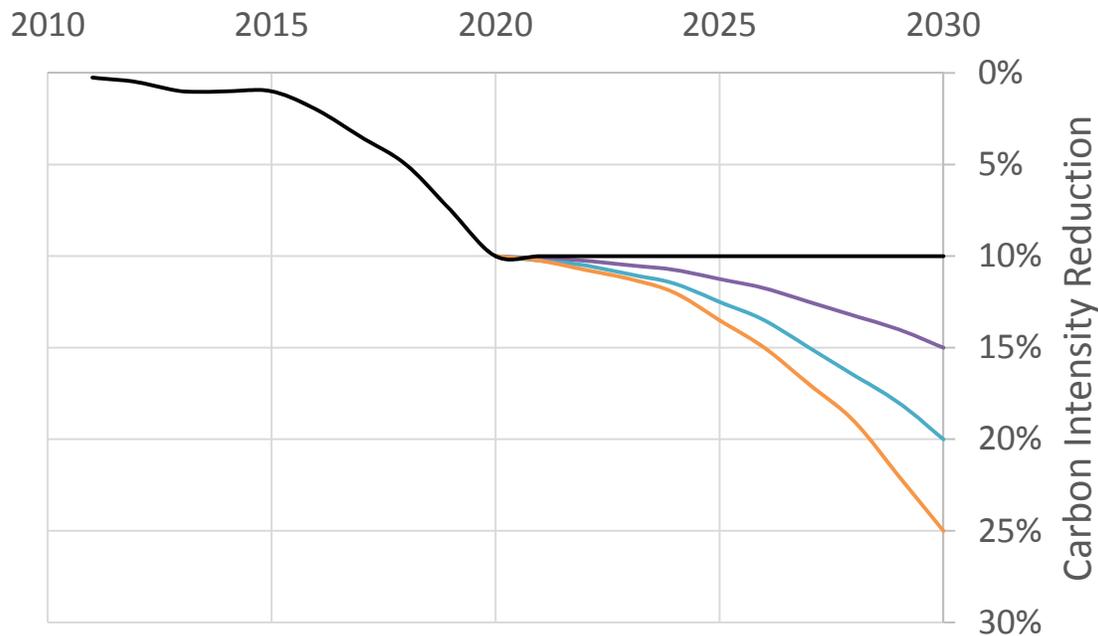
Low Carbon Fuel	Feedstocks / Applications	Considerations
Ethanol	Corn, sugar cane, molasses, sorghum, wheat, waste beverage, and cellulosic materials	<ul style="list-style-type: none"> • Generally blended to 10%; option to increase to as much as 15% by no earlier than 2025 • E85 option included in modeling
Electricity	Light-duty vehicles, off-road electrification, limited electrification in HD sectors	<ul style="list-style-type: none"> • Model assumes at least ZEV Program compliance; can exceed compliance • Off-road opportunities limited to forklifts and fixed guideway applications
Hydrogen	Light-duty vehicles	<ul style="list-style-type: none"> • Model assumes at least ZEV Program compliance; can exceed compliance
Natural gas	<ul style="list-style-type: none"> • Includes fossil and renewable natural gas • Includes CNG and LNG options • Focused on HD sectors 	<ul style="list-style-type: none"> • Model varies share of renewable natural gas (as a function of total natural gas) based on fuel demand and fuel price • Model includes fleet turnover considerations for more than 15 HD truck types (from EMFAC)
Biodiesel	Soy oil, canola oil, used cooking oil, corn oil, tallow	<ul style="list-style-type: none"> • Model includes blend limitations, with a maximum of B20 by 2030 • Assumed blending with conventional diesel and renewable diesel is OK
Renewable diesel	Tallow, soy oil, used cooking oil, other	<ul style="list-style-type: none"> • No blend limitations imposed

Stakeholders requested that ICF model LCFS compliance using four different carbon intensity targets for the year 2030 (see figure below for graphic representation of targets). ICF notes that there was no explicit feasibility analysis or test associated with any of these scenarios.

- 10% carbon intensity reduction. This represents the program’s current 2020 target, and we assume that the program is simply frozen at 2020 levels out to 2030.
- 15% carbon intensity reduction by 2030. The carbon intensity requirements between 2020 and 2030, a transition from a 10% target to a 15% target, are implemented on a non-linear basis, comparable to the shape of the compliance curve for 2011-2020.
- 20% carbon intensity reduction by 2030. The carbon intensity requirements between 2020 and 2030, a transition from a 10% target to a 20% target, are implemented on a non-linear basis, comparable to the shape of the compliance curve for 2011-2020.

- 25% carbon intensity reduction by 2030. The carbon intensity requirements between 2020 and 2030, a transition from a 10% target to a 25% target, are implemented on a non-linear basis, comparable to the shape of the compliance curve for 2011-2020.

Figure 3. LCFS Compliance Curves Implemented



Modeling Cap-and-Trade

ICF used the IPM Plus[®] model to develop compliance pathways to lower GHG emissions 40 percent below 1990 levels by 2030 under a range of emissions scenarios. The base model, IPM[®] provides a detailed representation of the US electric power sector, and is widely used by a range of private and public sector clients, in addition to being the platform used by EPA to support their analysis of the Clean Power Plan as well as other major air regulations under the Clean Air Act.¹⁷ IPM[®] provides long-term projections of the behavior of existing power plants (including dispatch, retrofit and retirement) as well as the build out of new conventional and renewable power plants in order to meet demand for electric generation energy and capacity requirements while complying with specified constraints, including air pollution regulations, transmission constraints, and plant-specific operational constraints. The model includes a representation of emission control technologies, the ability to fuel switch, and alter regional generation and capacity mix. These changes are all dynamically linked to a representation of wholesale power market operation, and therefore allow IPM[®] to build a detailed bottoms-up marginal abatement curve for the power sector that can vary significantly based on input assumptions, lending itself to exploring sensitivity analysis and policy design issues.

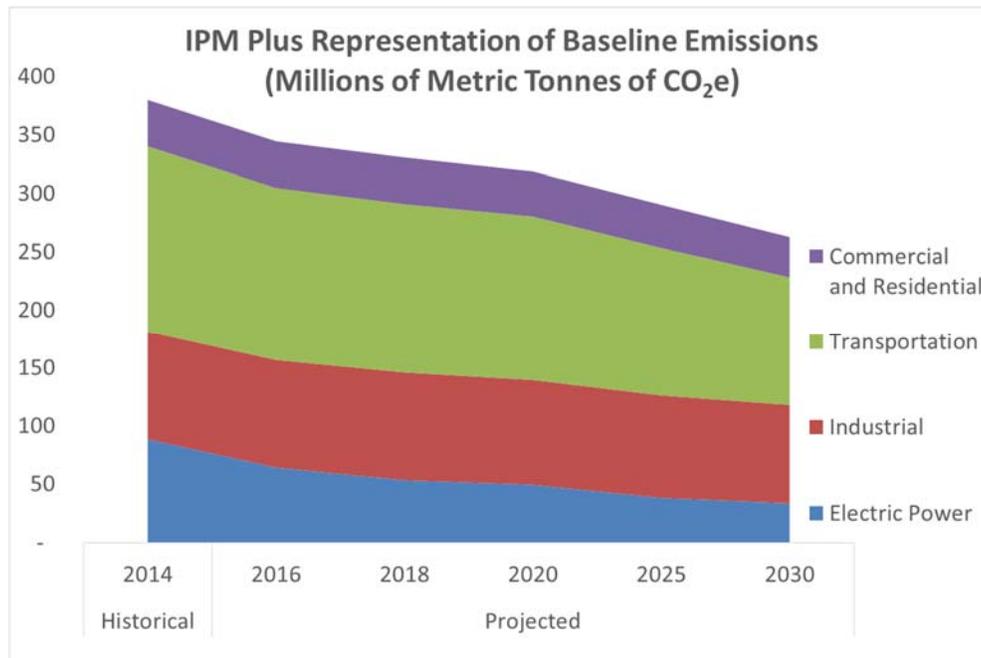
IPM Plus[®] extends this framework to include a representation of baseline emissions from the other covered sectors in California based on the most recent Scoping Plan categories¹⁸ – commercial and

¹⁷ EPA Power Sector Modeling, available online at www.epa.gov/airmarkets/power-sector-modeling.

¹⁸ 2030 Target Scoping Plan Update, available online at <http://www.arb.ca.gov/cc/scopingplan/scopingplan.htm>.

residential, transportation, and industrial, as shown in the figure below. ICF’s analysis focused on energy efficiency opportunities in the commercial and residential sector, and reductions in refinery emissions included in the industrial sector. All of the transportation sector emissions were based on outputs from our linked [LCFS modeling \(described in the previous sub-section\)](#). The [Appendix](#) includes more information about how the emission reductions from these sectors were estimated and incorporated into the modeling. If not explicitly mentioned, ICF employed reductions based on those included in the Scoping Plan Update. Further, ICF notes that our modeling includes emission reductions achieved via offsets, which were available at the price floor. Offset purchases were limited to 8% of the total cap in each year (which means that the availability of offsets decreases every year on an absolute basis).

Figure 4. GHG Emissions in California out to 2030 under an Expanded and Extended Cap-and-Trade Program-



While the model solves for baseline Power Sector emissions based on input assumptions, the baseline emissions for the other covered sectors are developed through a combination of public sources and ICF’s proprietary research and modeling capabilities.

Sectoral GHG emissions abatement opportunities are represented within IPM Plus® in the form of marginal abatement cost curves (MACC). These curves were developed through detailed analyses of the technical costs and reduction potential of the abatement options available to a particular source of emissions. These curves include the effects of market factors, such as customer resistance, average automobile turnover, etc. Given a particular emissions mass cap across all covered sectors represented in IPM Plus® emissions baseline, and MACC data, IPM Plus® walks up the sectoral MAC curves, choosing progressively more expensive abatement options until the cap is no longer exceeded, such that the total production cost over the forecast period (2016–2030) is minimized and all other model constraints are met.

Summary of Findings

Modeling Results

The table below summarizes ICF’s findings across the various modeling runs with various levels of gasoline and diesel consumption, tied to different carbon intensity targets in an expanded LCFS program.

Table 2. Projected Allowance Pricing in the Cap-and-Trade Market under various LCFS Compliance Scenarios

Scenario	Historical		Projected Allowance Price (\$/MT)			
	2014	2016	2018	2020	2025	2030
10% CI reduction		11	12	33	40	52
15% CI reduction	10	11	12	29	36	47
20% CI reduction		11	12	15	18	23
25% CI reduction		11	12	15	18	23

ICF finds that allowance prices remain at the floor through the 2018 run year, reflective of current market pricing, which is not anticipated to change over the next several years. Starting in 2020, prices ramp up reflecting tightening standards and near-term over-compliance to smooth out compliance costs towards the second half of the forecast period. And as expected, the model run with a 10% carbon intensity reduction features higher allowance costs than the cases including the more stringent LCFS targets.

ICF stresses the importance of the trends and relative price difference between the estimates shown in the table above. The trend and relative difference are more important than the difference in absolute prices because they reveal that we are in a moderately steep part of the marginal abatement cost curve, which contributes to higher allowance prices. Our modeling is more robust for the power and transportation sectors. As a result, it is conceivable that we have over-estimated the market clearing price for cap-and-trade. With that in mind, the trend is clear: The addition of a more stringent LCFS serves to lower the emissions baseline for the transportation sector, which in turn reduces the pressure on the mass cap. All else equal, this results in a lower step on the MAC curve being selected and therefore lower compliance costs, as illustrated by the lower market clearing carbon price in the scenarios with more stringent carbon intensity targets.

Overview of Compliance Costs in the Transportation Sector

Compliance costs are difficult to estimate, because we must make assumptions about how regulated entities will comply. And our modeling limits us to estimates for clearance prices for the cap-and-trade market and the LCFS market. These clearance prices represent the *marginal abatement cost* in each market, rather than the *average abatement cost* in each market. In other words, the market clearing price or marginal abatement cost for the cap-and-trade market has a reported range of \$23—52- per ton in 2030. There are reductions, however, that will occur at lower prices in the year 2030. Similar

observations can be made in the LCFS market where it is likely that credits prices will be in the range of \$150—200 per ton in most of the scenarios considered by 2030; however, not all credits will necessarily be purchased at that price. This is the difference between the marginal and average price in each market.

To simplify the comparison of compliance costs across scenarios, ICF has simply summed the compliance costs of Cap-and-Trade and LCFS. With regard to the former, the compliance costs are reported as the product of the transportation sector emissions in a given year and the market clearing price. With regard to LCFS, the compliance costs are reported as the product of the deficits generated in a given year and the forecasted credit price in that year. The table below illustrates our findings for the scenarios with a 10%, 15%, and 20% carbon intensity target in 2025 and 2030. The compliance costs are also shown on a per barrel basis for illustrative purposes. ICF notes that these costs represent marginal costs for petroleum-based refineries assuming all credits are purchased, as opposed to refineries generating any credits through some internal action.

Table 3. Estimated Compliance Costs in the Transportation Sector for LCFS and Cap-and-Trade

Scenario	Compliance Costs (\$M)			
	2025		2030	
	Absolute	\$/BBL	Absolute	\$/BBL
10% CI reduction	\$8,300	\$27.7/BBL	\$8,000	\$29.8/BBL
15% CI reduction	\$8,700	\$29.6/BBL	\$9,900	\$38.0/BBL
20% CI reduction	\$6,300	\$22.5/BBL	\$7,800	\$32.7/BBL

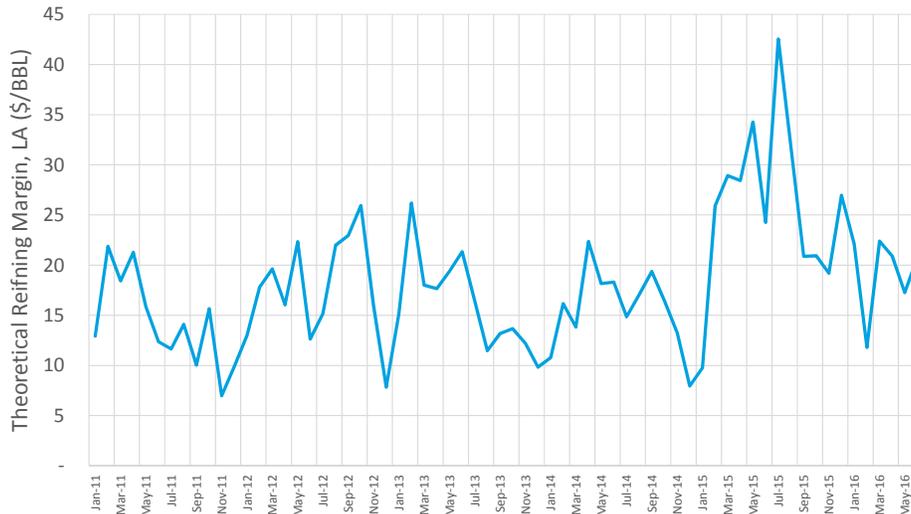
The estimated absolute compliance costs are within 5—30% of each other in 2025 and 5—20% of each other in 2030. And the compliance costs on a per barrel basis are within 25% of each other by 2030. Given the uncertainty associated with forecasting both the cap-and-trade market and the LCFS market out to 2030, we consider these ranges to reflect the likelihood of similar overall compliance costs across each of the three scenarios included in the table above. ICF has excluded the scenario with a 25% carbon intensity target for discussion here because we do not have sufficient confidence in the accuracy of forecasting LCFS credit prices at that stringent level of a carbon intensity target.

As noted previously with the market clearing prices, ICF estimates for the absolute value of compliance costs are not as important, or as accurate as the *relative differences* between scenarios. For instance, on an absolute basis we find that the scenarios with more stringent carbon intensity standards may actually have lower overall compliance costs by 2025. However, this result is linked to how the modeling is performed. For instance, the IPM Plus Model has banking and trading provisions consistent with the current structure of the cap-and-trade program. In some regard, the model works backwards to optimize compliance—and in 2030, the model “sees” a potential short-fall of reductions required to meet the 2030 target. The model subsequently seeks additional GHG reductions in earlier years to bank and use in later years. This drives up the price in the interim years, which is why we see a larger gap between the scenario with a 10% carbon intensity target and the scenarios with a 15% and 20% carbon intensity target.

For the sake of comparison, we have included a figure below which shows the theoretical refining margin for refineries on the West Coast on a per barrel basis. The theoretical refining margin is referred

to as 3-2-1 crack spread, representing the costs of producing two barrels of gasoline and one barrel of diesel from three barrels of crude oil. As shown in the figure below, the refining margins have been higher than their historical averages over the past 12-18 months as a result of refinery outages in California, which has also led to higher prices at the pump and is unrelated to either the cap-and-trade program or the LCFS program. Today’s LCFS credit price and allowance prices in the cap-and-trade market, for instance, yield a compliance cost of about \$5–6 per barrel.

Figure 5. Theoretical Refining Margin at West Coast Refineries, 2011--2016



ICF also notes that this discussion is limited to compliance costs in the transportation sector, with some of our assumptions linked to the current structure of these markets. In the LCFS market, for instance, we have not allowed credit prices to go above the \$200/ton maximum included in the cost compliance mechanism implemented by CARB as part of the re-adoption process in 2015. As noted elsewhere, this is not a hard cap—a regulated party could choose to forego the public process included via the credit clearance mechanism and pay more than the \$200/ton. ICF has no comment on the likelihood of this happening, rather, we are noting that our modeling does not allow LCFS credit prices to exceed \$200/ton.

Fuel Diversification and Petroleum Displacement

The regulated parties in the transportation sector, mainly refiners, are largely price takers in the Cap-and-Trade market. In other words, they accept prevailing market prices for allowances in large part because of the higher abatement costs in the transportation sector. As a result of this position, abatement in the transportation sector is pushed out until future years when the marginal abatement costs are higher. The side effect of this anticipated market response is the persistence of a petroleum-dependent transportation sector. With an LCFS in place, we expect to see a stronger price signal in the transportation sector, thereby inducing opportunities for fuel diversification and petroleum displacement. The scenarios modeled bear that reasoning out, as shown in the table below.

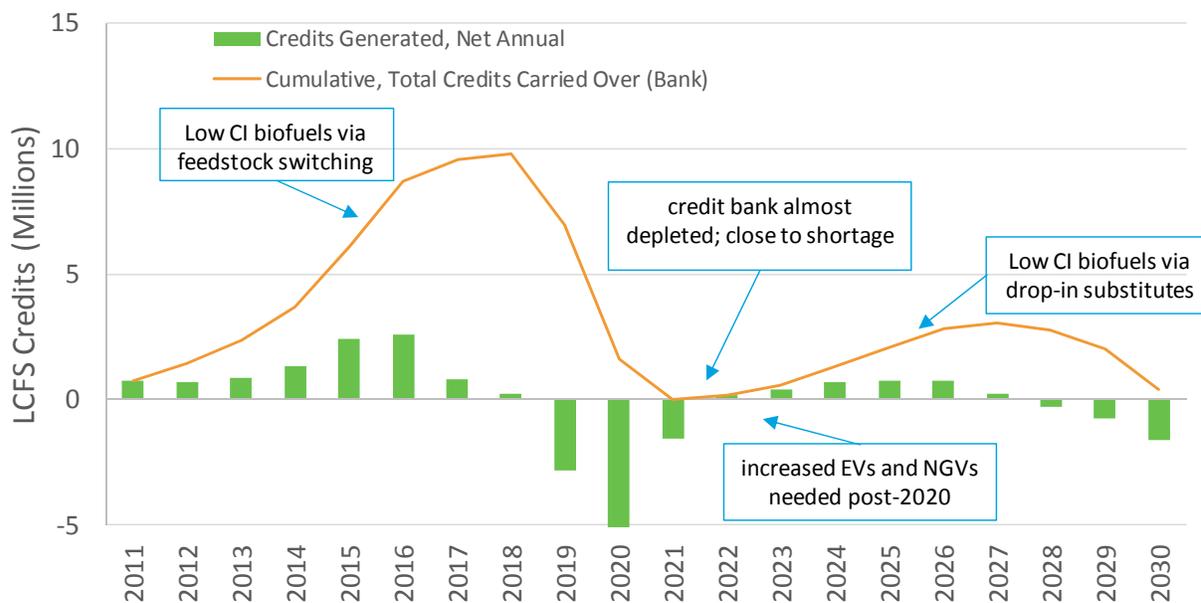
Table 4. Petroleum Displacement in Different LCFS Compliance Scenarios

Scenario	Petroleum Displacement (compared to 10% CI reduction)		
	2022	2025	2030
15% CI reduction	12%	15%	18%
20% CI reduction	13%	19%	26%
25% CI reduction	14%	20%	26%

These results show the petroleum reductions achieved as a percentage reduction from a scenario with a 10% carbon intensity target in 2030. As expected, the more stringent carbon intensity reductions yield greater fuel diversification, with the benefits increasing substantially between a 15% carbon intensity target and a 20% carbon intensity target.

The figure below highlights the need for fuel diversification, in part because of the potential challenges associated with achieving the more stringent carbon intensity targets assumed for LCFS compliance. The figure shows the balance of credits and deficits on a cumulative and annual basis in the scenario with a 15% carbon intensity reduction target. The green bars represent the balance of credits and deficits generated on an annual basis, while the orange line represents the cumulative or total credits generated or banked over the program’s life. If the orange line falls below the zero axis, then it indicates that the program will not clear.

Figure 6. LCFS Compliance with the 15% Carbon Intensity Target in 2030



Compliance with the LCFS is limited by the extent to which biofuels can be blended with the existing fuel supply and fleet turnover. Biofuel blending is broadly characterized by both feedstock switching and petroleum displacement via increased biofuel blending. Fleet turnover, determines the rate at which fuels like electricity, hydrogen, and natural gas can displace petroleum. The figure above highlights the various stages of the challenge facing transportation fuel markets:

- In the early stages of the program, we have observed increased biofuel blending, with a focus on feedstock switching in ethanol markets, to help drive compliance. There has been some displacement via biodiesel and renewable diesel blending, but feedstock switching is the largest share of credits generated to date. This helps drive up the bank of credits into the 2017—2018 timeframe.
- At the peak of the bank, in 2017—2018, the market opportunities for biofuel blending become more limited as the carbon intensity target becomes more stringent. As a result, the bank starts to get drawn down to maintain compliance with the program. This trend reaches its largest negative slope in 2020 when the annual deficits generated (the green bars) peaks.
- Biofuel blending opportunities increase in concert with more potential for fleet turnover (thereby enabling more deployment of electric vehicles, natural gas vehicles, and hydrogen fuel cell vehicles) post-2020, dragging the annual balance of credits and deficits in a positive direction, thereby increasing the bank of credits available in the market again.
- By the 2025 timeframe, the combination of fleet turnover (enabling alternative fuel vehicle deployment) and biofuel blending opportunities helps level out the availability of credits in the market.

Post-2020 Considerations

The dominant market position of petroleum-based fuels, with more than 90% of the market today, presents unique challenges to strategies that reduce emissions in the transportation sector. For instance, the time and capital outlays required to develop and deploy alternative fuels and supporting fueling infrastructure are significant. Similarly, fleet turnover is slow—even in 2015 when new light duty vehicle sales surpassed 2 million units, this represented about 7% of the entire fleet of vehicles statewide. In other words, the strategies required to reduce emissions in the transportation sector require a lead time that is at odds with the short-run price signal of a cap-and-trade program.

Regardless of the ingenuity of entrepreneurs and technology providers to develop innovative strategies to reduce GHG emissions in the transportation fuels and vehicle markets, investors are unlikely to bear the risk of an uncertain allowance price. Furthermore, the near-term price signal from carbon allowances is insufficient to induce investments in the transportation sector where carbon reduction is higher cost than what can be achieved in other sectors.¹⁹ Complementary measures like the LCFS are still needed to spur long-term investments in fossil fuel alternatives.

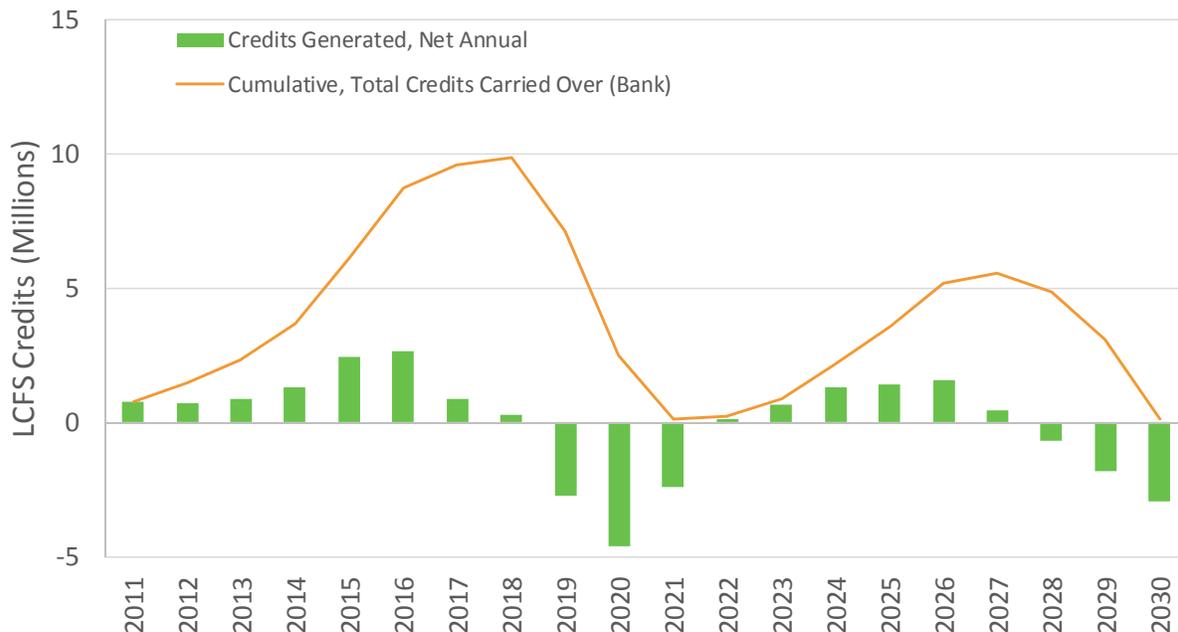
The LCFS program encourages the deployment of a diverse mix of low carbon fuels, thereby increasing the competitiveness in the transportation fuels market. The program also affords refiners the opportunity to comply via refinery efficiency improvements and other upstream measures, including innovative crude production. In our modeling above, the case with more stringent LCFS requirements yield lower Cap-and-Trade allowance prices and significantly higher alternative fuel penetrations, displacing 11—17% of the gasoline pool and 28—48% of diesel demand. In the case with a less stringent

¹⁹ ICF notes that the cost perspective assumed here is the total cost associated with deploying technologies that abate carbon. In some cases, such as electric vehicles, it is conceivable that incentives and low electricity prices yield low or negative carbon abatement pricing from the consumer perspective.

LCFS, we see business-as-usual gasoline and diesel displacement, linked to existing programs such as light-duty GHG standards, medium/heavy-duty fuel efficiency standards, and the ZEV Program.

The figure below, similar to Figure 6, but for the scenario with a 20% carbon intensity target, demonstrates the challenge of implementing a LCFS post-2020. The compliance outlook is considerably different in the scenarios that have more stringent carbon intensity targets.

Figure 7. LCFS Compliance with the 20% Carbon Intensity Target in 2030



The primary difference between Figure 6 and Figure 7 is how we forecast the market to respond to a more stringent standard: Fleet turnover picks up as does biofuel blending; but these are both rate-limiting, yielding a challenging compliance outlook in the 2028-2030 timeframe. Similarly, if the standard is ramped up too quickly post-2020, then it is distinctly possible that the market will not clear (i.e., there will not be sufficient credits to offset deficits). This is shown in the inflection point in 2022, where the bank (represented as the orange line) nears zero. If the carbon intensity target in that year is even slightly higher, implemented for instance by using a straight-line approach between 2020 and 2030 carbon intensity targets, then ICF anticipates a distinct chance of program failure. This is not to say that the program will fail: Rather, the objective is to highlight that the compliance curve should be developed in a way that enables fuel diversity and investment outlays to occur in a time frame that enables a robust market for LCFS credits.

While the LCFS does promote fuel diversity, with the potential to decrease gasoline and diesel prices, there are potentially countervailing market factors impacting refiners that operate in an increasingly carbon-constrained market. In the same way that refinery outages and reduced refinery runs impact fuel prices today, so too can a smaller market. The underlying economic assumptions associated with downward price pressure as a result of fuel diversity are linked to a constant or only marginally reduced supply of fuels. In other words, this ignores the fact that refineries have the option to shut down rather than simply reduce runs. And as the refining industry contracts, the remaining market actors will still

wield significant market influence, with the ability to increase prices as part of a captive market. ICF's estimates for the likely petroleum displacement resulting from cap-and-trade and an extended LCFS program to 2030 are unlikely to yield this type of outcome.

After 40 years of trying, it is obvious that commercializing low-carbon fuels is a challenging task that requires many types of programs working together to address a wide range of barriers. Markets and price signals are insufficient on their own. The LCFS is able to address many of the key barriers for most low-carbon fuels including development of new fuels, distribution systems, fueling stations and consumer incentives for lower carbon fuels. The LCFS combined with Cap-and-trade results in advancement of low carbon fuel technologies and improvement of the business cases for low carbon fuel producers, distributors, station operators and/or end-users compared to cap-and-trade alone.

The LCFS also provides the clearest and most inclusive policy signal to low carbon fuel providers, and avoids the shortcomings of most policies or regulations that focus myopically on one particular strategy over another, such as a biofuel blending mandate. Further, it allows for the most efficient allocation of capital and investment without relying on government intervention directing investment to a particular fuel. The lack of competitiveness in the transportation fuels market in California is highlighted by price spikes resulting from refinery outages and other events. Given that the transportation sector is nearly 95 percent dependent on petroleum-based fuels, it is to be expected that the early stages of a transition to greater alternative fuel use, spurred by the LCFS program, will have some "start-up" costs that do not fully translate into benefits until the post-2020 timeframe. By 2030, ICF anticipates that increased utilization of infrastructure assets, increased competitiveness in fuel markets, increased economies of scale in alternative fuel production, and continued incremental technological improvements will yield downward pressure on petroleum based fuel pricing.

Appendix: Overview of Cap-and-Trade Modeling Results

The IPM Plus considers emissions from the following sectors: electric power, industrial, transportation, commercial and residential energy, uncapped sectors, and offsets. For the purposes of ICF's analysis, we considered the business as usual emissions trajectories from CARB's Scoping Plan Update. Emissions in the transportation sector were considered separately as part of the LCFS modeling. The other reduction opportunities were in the electric power sector, large emitters in the industrial sector (with a focus on refineries given data limitations), and energy efficiency in the commercial and residential sector. ICF's approach to develop the marginal abatement cost curves in each of these sectors is discussed briefly below. ICF notes that offsets were available at the price floor, set at \$10 per ton in 2013 and rising 5% (real) every year thereafter; offsets were also limited to 8% of the total cap in each year (which means that the availability of offsets decreases every year on an absolute basis).

Electric Power Sector

IPM[®] provides a detailed representation of the US electric power sector, and is widely used by a range of private and public sector clients, in addition to being the platform used by EPA to support their analysis of the Clean Power Plan as well as other major air regulations under the Clean Air Act.

IPM[®] provides long-term projections of the behavior of existing power plants (including dispatch, retrofit and retirement) as well as the build out of new conventional and renewable power plants in order to meet demand for electric generation energy and capacity requirements while complying with specified constraints, including air pollution regulations, transmission constraints, and plant-specific operational constraints. The model includes a representation of emission control technologies, the ability to fuel switch, and alter regional generation and capacity mix. These changes are all dynamically linked to a representation of wholesale power market operation, and therefore allow IPM[®] to build a detailed bottoms-up marginal abatement curve for the power sector that can vary significantly based on input assumptions, lending itself to exploring sensitivity analysis and policy design issues.

Refining in the Industrial Sector

Data from EPA's Greenhouse Gas Reporting Program was utilized to break out emissions by refinery across California according to 2014 reported data, establishing a baseline in carbon dioxide equivalent. Emissions were split by major refinery process (e.g., flaring, catalyst coking, vents, etc.) and combustion unit (e.g. heaters and boilers). Allocating combustion emissions between heaters and boilers was performed using available boiler/heater capacities averaged across the Petroleum Administration for Defense District (PADD) level and applied to California.

With the emissions baseline established, a list of mitigation technologies were identified for implementation at refineries. For each technology the level of emissions reduction (%), the cost to implement²⁰, and the penetration rate (i.e., percentage of refineries already implementing this reduction

²⁰ Costs will be represented in 2016 dollars and will not be adjusted further.

measure) were estimated. Each mitigation technology was then applied to a specific emission source, either at a refinery process level (e.g., flaring, catalytic coke, etc.) or to a portion of combustion emissions (i.e., boilers and heaters). The results were tailored to California-specific refinery characteristics. For example, due to stricter air regulations, refineries in California tend to have a higher penetration rate of emissions reducing technology, so to the extent possible, characteristics such as these were taken into consideration.

The economics of mitigation technologies and practices were developed by applying the mitigation technologies to emissions sources according to levels of applicability identified during research and supplemented by expert judgment. For example, it was assumed that for boiler emissions, first a steam balance reduction measure would be applied, then potential CHP opportunities, and then finally a set of further boiler specific mitigation options. At each level, the boiler emissions baseline was carefully considered and adjusted based on the subsequent level of applicability. The output was the cost of abatement and the volume of abatement by emissions source.

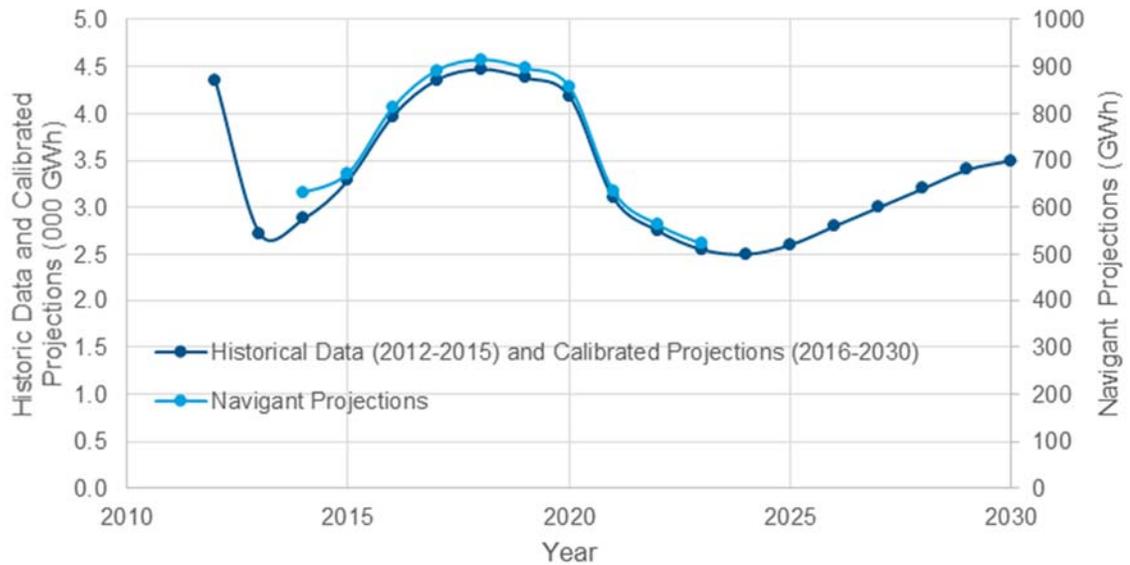
Energy Efficiency in Commercial & Residential Sector

The MAC curves for energy efficiency were developed based on a review of the costs and savings of energy efficiency programs from both investor owned and public utilities in California. The data for the investor owned utilities was gathered from the California Energy Efficiency Statistics Database²¹ while the data from the public utilities was taken from CPUC reports.²² From this data, total costs and savings estimates were gathered on a program level for 2012—2015. These pairs of program and cost estimates were used as the steps for generation of the MAC curves, and were ordered from most to least cost effective. A MAC curve was generated for each year, and a comparison of these curves indicated that the 2013 curve was the most representative of the average savings trends for the four years examined. Therefore, the 2013 curve was used to develop projections for 2016—2030.

To create the MAC curves for the forecast period, the 2013 curve was scaled linearly based on the projections for energy efficiency savings from Navigant included in the 2015 CPUC energy efficiency report. This was done by first calibrating the Navigant projections to the actual savings data for the two years available, 2014 and 2015. Then, the 2013 curve was scaled for each of the forecast years so that the total projected savings agreed with the calibrated Navigant projections. Since the Navigant projections were only available out to 2023, the total savings projections for the years after (2024-2030) were estimated by assuming that the trend line for a damped sine wave that is observed in the projections from 2014—2023 continues into the future.

²¹ California Energy Efficiency Statistics Database; available online at <http://eestats.cpuc.ca.gov/>.

²² For instance, Energy Efficiency in California's Public Power Sector, A 2015 Status Report



IPM Sectoral Results from LCFS Compliance Scenarios

The subsequent graphs show the sectoral GHG emissions results for the various compliance scenarios modeled.

Figure 8. IPM Sectoral GHG Emission Results, 10% Carbon Intensity Reduction

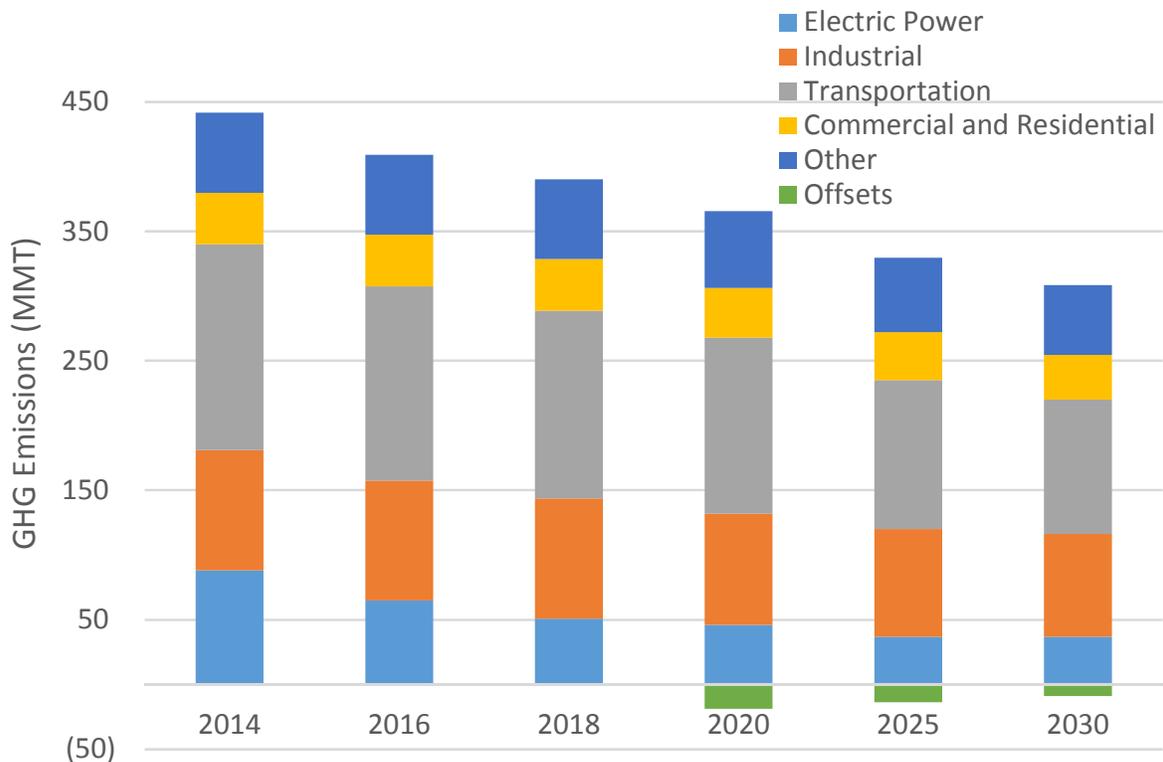


Figure 9. IPM Sectoral GHG Emission Results, 15% Carbon Intensity Reduction

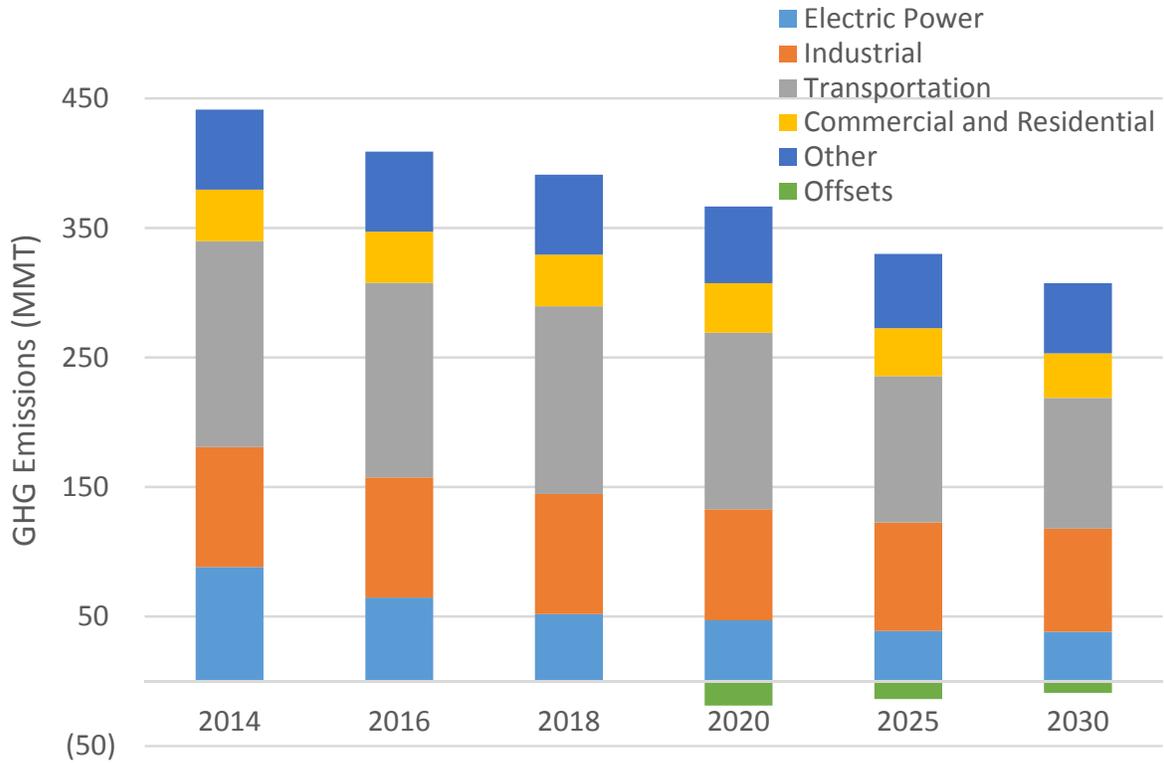


Figure 10. IPM Sectoral GHG Emission Results, 20% Carbon Intensity Reduction

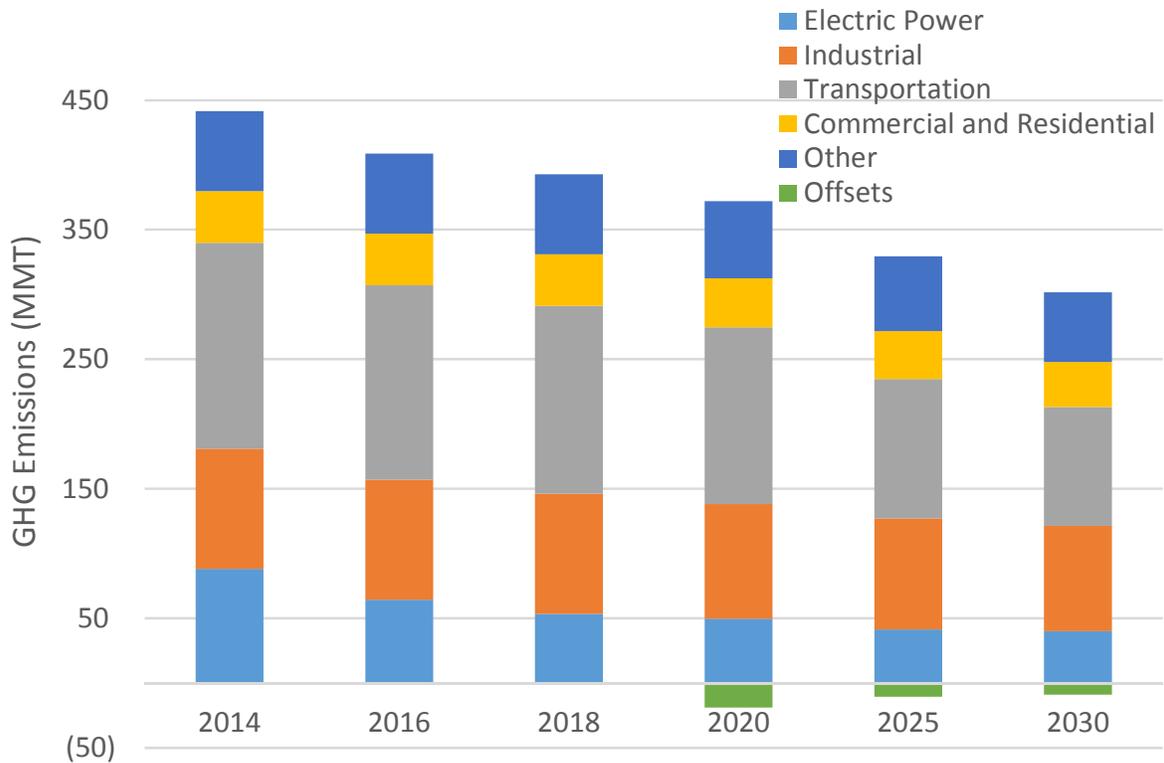


Figure 11. IPM Sectoral GHG Emission Results, 25% Carbon Intensity Reduction

