California's Low Carbon Fuel Standard: Compliance Outlook for 2020

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Prepared for:

CalETC
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In Partnership with:

National Biodiesel Board

California Natural Gas Vehicle Coalition

Advanced Biofuels Association

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Abbreviations and Acronyms

ABFA	Advanced Biofuels Association
BD	Biodiesel
BEV	Battery Electric Vehicle
CalETC	California Electric Transportation Coalition
CARB	California Air Resources Board
CARBOB	California Reformulated Blendstock for Oxygenate Blending
CCS	Carbon Capture and Storage
CEC	California Energy Commission
CNCDA	California New Car Dealers Association
CNG	Compressed Natural Gas
CNGVC	California Natural Gas Vehicle Coalition
CO2	carbon dioxide
CPUC	California Public Utilities Commission
DOE	Department of Energy
E2	Environmental Entrepreneurs
EER	Energy Economy Ratio
EPA	Environmental Protection Agency
EVSE	Electric Vehicle Supply Equipment
FCV	Fuel Cell Vehicle
gge	gasoline gallon equivalent
LCFS	Low Carbon Fuel Standard
LNG	Liquefied Natural Gas
MY	Model Year
NBB	National Biodiesel Board
NRDC	Natural Resources Defense Council
OECD	Organisation for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
OTSG	once-through steam generator
PEV	Plug-in Electric Vehicle
PHEV	Plug-in Hybrid Electric Vehicle
RD	Renewable Diesel
RFS2	Renewable Fuel Standard
ULSD	Ultra Low Sulfur Diesel
ZEV	Zero Emission Vehicle

Executive Summary

Adopted in 2007, California's Low Carbon Fuel Standard requires a 10 percent reduction in the carbon intensity of transportation fuels by 2020, as measured on a lifecycle basis. The goals of the program are to reduce greenhouse gas emissions from the transportation sector, diversify the transportation fuels sector, and to spur investment and innovation in lower carbon fuels.

The LCFS is designed as a performance-based standard using flexible market-based mechanisms that allow regulated parties to select the most cost-effective pathways to achieve compliance. Fuels that have a lower carbon intensity than gasoline or diesel generate LCFS credits. Regulated parties, such as refiners, have the option of producing or blending low carbon fuels, or purchasing credits from other fuel providers, including, but not limited to biofuel producers, natural gas infrastructure providers, electric utilities, and hydrogen producers.

This report represents the first phase of a two-phase, year-long project assessing the economic and environmental impacts of compliance with California's LCFS out to 2020. This phase focuses on the development of compliance scenarios based on market research, consultation with stakeholders, and market forecasts based on best estimates of fuel availability. These compliance scenarios are used to convey the outcomes of our research and analysis: namely, that the LCFS requirements can be achieved through modest changes in the diversity of transportation fuels supplied to California. The second phase of the work will focus on the economic and environmental impacts of these compliance scenarios, including parameters such as gross domestic product, jobs, and avoided damage costs.

ICF developed two scenarios – Scenario 1 and Scenario 2 – to capture the potential market responses to achieve compliance with the LCFS. ICF emphasized probabilistic outcomes for each alternative fuel type based on market constraints and opportunities: where appropriate, ICF defaulted to more conservative estimates of fuel and vehicle penetrations. A stakeholder panel developed a third compliance scenario referred to as the LCFS Enhanced Scenario, which ICF will also be modeling as part of the second phase of our work. The key highlights of the LCFS compliance scenarios include:

- **Compliance with the LCFS can be achieved through modest changes and a diverse supply of transportation fuels.** Broadly speaking, compliance is achieved through biofuel blending (with both gasoline and diesel) and through the deployment of advanced vehicle technologies that use natural gas, electricity, and hydrogen. In both scenarios, the majority of LCFS compliance is achieved through blending biofuels. However, compliance in Scenario 1 depends on more aggressive forecasts for advanced vehicle technologies than Scenario 2, thereby putting less pressure on the demand for biofuels. Regardless, both scenarios were developed to reflect the market-based flexibility of the regulation and recent market developments.
- **The alternative fuels market is evolving rapidly and in unforeseen ways, and the LCFS is driving investment in low carbon ethanol, biodiesel, renewable diesel, and biogas.** ICF has accounted for a variety of market developments in the compliance scenarios. For instance, the immediate availability of lower carbon biofuels such as biodiesel from corn oil, waste greases, and animal fats; renewable diesel from tallow; and ethanol from molasses. Although cellulosic biofuels have been produced at a slower-than-expected rate, these lower

carbon biofuels are available to California in significant quantities today and supply is forecasted to increase dramatically over the next several years. Each of these fuels has a carbon intensity less than 35 gCO_2e/MJ, representing a more than 60 percent reduction in carbon intensity compared to the LCFS compliance schedule. Apart from biofuels, increasing natural gas supplies and lower fuel pricing than diesel have renewed interest in natural gas in the transportation sector. Meanwhile, although plug-in electric vehicles are being purchased by California drivers at modest rates – in some areas, demand has been high enough to cause vehicle supply shortages – electricity consumption is unexpectedly making contributions towards LCFS compliance in these early years of the program.

- **Over-compliance in early years of the regulation (through 2016, at least) is critical, and a significant number of excess credits have already been generated.** As noted previously, LCFS credits can be banked and traded, and do not lose value. In fact, despite the uncertainty regarding the LCFS (e.g., legal challenges) and a fragile economic recovery, the LCFS market generated nearly 1.3 million excess credits by the end of 2012. Because of the way the LCFS compliance schedule is designed, over-compliance in early years is critical towards meeting compliance in later years (e.g., 2019 and 2020). In Scenario 1 and Scenario 2, for instance, credits are banked through 2017 and 2016, respectively. In subsequent years, the banked credits are drawn down to achieve compliance.
- **The diesel sector will likely generate more than its fair share of credits.** ICF developed scenarios that reflect the flexibility of the LCFS guidelines: namely, credits are fungible. It does not matter if credits are generated using fuels that substitute for gasoline or fuels that substitute for diesel. Forecasted diesel consumption in California indicates that diesel will generate about 20 percent of deficits in the LCFS program. However, fuels that substitute for diesel, including biodiesel, renewable diesel, and natural gas, have the potential to generate 40-55 percent of LCFS credits.
- **Biodiesel can make a significant contribution towards LCFS compliance.** Although biodiesel consumption in California has been modest in recent years, there is significant potential to blend biodiesel at lower levels (e.g., 5 percent to 20 percent by volume) with conventional diesel and generate a substantial number of LCFS credits. Infrastructure providers are already responding to this potential, and based on ICF research and stakeholder consultation, the industry is rapidly increasing the ability to store and blend biodiesel at petroleum terminals and at refineries.
- **Renewable diesel will make a modest contribution towards LCFS compliance, even at low volumes.** With no additional distribution infrastructure or refueling infrastructure costs, and no limitations on consumption in vehicles, renewable diesel is an attractive option for LCFS compliance. Furthermore, it is available in significant quantities today. Even at conservative forecasts of 150 million gallons renewable diesel delivered to California by 2020, renewable diesel could generate about 8 percent of the LCFS credits required to achieve compliance.
- **Natural gas consumption will increase rapidly in California and play a significant role in LCFS compliance.** When the LCFS was first developed in 2008, natural gas was expected to play a niche role in compliance. However, the increase in domestic natural gas supply has helped maintain a persistent price differential between natural gas and diesel. Combined with increased engine offerings in medium- and heavy-duty applications, particularly in the goods movement sector, natural gas consumption in the transportation sector is poised to increase significantly and rapidly. The expansion of natural gas consumption in the transportation sector will also facilitate a transition to biogas from landfills, for instance. With a carbon intensity less than 30 gCO_2e/MJ, even modest

penetrations of biogas (e.g., 10 percent of California's natural gas consumption) are feasible.

- **Small modifications to the LCFS can have a substantive impact on compliance.** ICF also included estimated credits that can be generated through potential modifications to the LCFS, namely electricity used in fixed guideway applications (e.g., light rail in transit) or forklifts. Even though these credits are modest, they decrease the necessity of blending potentially more costly low carbon biofuels or accelerating the adoption of advanced vehicle technologies.

1. Introduction

1.1. California's Low Carbon Fuel Standard

In 2007 Governor Schwarzenegger signed Executive Order S-01-07 establishing California's Low Carbon Fuel Standard (LCFS), which requires a ten percent reduction in the carbon intensity of transportation fuels by 2020. Carbon intensity is measured in grams of carbon dioxide equivalents (gCO_2e) per unit energy (MJ) of fuel and is quantified on a lifecycle or well-to-wheels basis. In 2009, the California Air Resources Board (CARB) adopted the LCFS regulations. The program has been implemented and enforced since the beginning of 2011.

The LCFS is a flexible market-based standard implemented using a system of credits and deficits: transportation fuels that have a higher carbon intensity than the compliance schedule yield deficits, and fuels that have a lower carbon intensity generate credits. Regulated parties are required to have a net zero balance of credits and deficits annually. Credits can be banked and traded without limitations, and credits do not lose value. Transportation fuels that have a lower carbon intensity than the compliance schedule include ethanol, biodiesel, natural gas, electricity, and hydrogen. CARB quantifies and publishes carbon intensity values for all fuel pathways.

The entities that generate credits and deficits are referred to as regulated parties, an d the entity varies depending on the fuel. For instance, refiners are typically the regulated party for gasoline and diesel. Alternative fuel providers are referred to as opt-in regulated parties. The obligated parties vary considerably, including entities such as fuel producers and fueling station owners.

The Nuts and Bolts of LCFS

Carbon intensity is measured on a lifecycle or well-to-wheels basis in units of grams of carbon dioxide equivalent per unit energy of fuel (gCO2e/MJ).

The LCFS is implemented using a system of **credits and deficits**, with each credit representing one metric ton of reduction. Credits are generated by transportation fuels that have a carbon intensity lower than the compliance schedule (ranging from about 98 gCO2e/MJ in 2013 to 89 gCO2e/MJ in 2020) and deficits are generated by gasoline and diesel.

At the end of each year, compliance is achieved by offsetting deficits with credits. Credits can be banked and traded, and they do not lose value over time.

1.2. Scope of Work

ICF was retained by the California Electric Transportation Coalition (CalETC), the California Natural Gas Vehicle Coalition, the National Biodiesel Board (NBB), the Advanced Biofuels Association (ABFA), Environmental Entrepreneurs (E2), and Ceres to assess the macroeconomic impacts of the LCFS, using parameters such as gross domestic product and changes in jobs. The project has two phases:

- In the first phase of work, ICF developed scenarios that represent a range of likely outcomes towards LCFS compliance. These scenarios are intended to capture the range of potential market developments that would lead to LCFS compliance given our current outlook on the transportation fuel marketplace. In any forward-looking exercise, it is important to note that there is some uncertainty associated with the availability of lower carbon transportation fuels.

- In the second phase of work, ICF is using the REMI model to analyze the associated macroeconomic impacts of the LCFS compliance scenarios developed in Phase 1. Furthermore, ICF is quantifying and monetizing the GHG emission reductions, criteria pollutant emission reductions, and petroleum reductions associated with each compliance scenario.

This report focuses on the first phase of our work and includes the following sections:

- **Section 2** outlines the methodology that ICF employed, with information regarding conventional fuel projections, how regulatory overlap was included, and compliance strategies considered.
- **Section 3** provides an overview of LCFS compliance scenarios
- **Section 4** provides a more detailed review of the research, analysis, and market developments that were used to develop the LCFS compliance scenarios.
- **Section 5** provides a brief overview of the project's next steps, including a more detailed discussion of the macroeconomic modeling ICF is conducting using the REMI model.

2. Methodology: Scenario Development

ICF developed three (3) LCFS compliance scenarios in the first phase of our work to estimate the macroeconomic impacts of the LCFS: Compliance Scenario 1 and Compliance Scenario 2 were developed by ICF in collaboration with a Stakeholder Review Panel. The stakeholder group developed the final compliance scenario, referred to as the LCFS Enhanced Scenario. The following subsections review the methodological issues identified in the process of developing LCFS compliance scenarios.

2.1. Stakeholder Input

The table below highlights the organizations that provided input via the Stakeholder Review Panel, which includes representatives from the utilities, the natural gas industry, and biofuel producers.

Exhibit 1. LCFS Study Stakeholder Review Panel

Stakeholder Review Panel Member	Areas of Expertise
California Electric Transportation Coalition	• Electricity transmission and distribution • Electric vehicles and hydrogen fuel cell vehicles • Renewable energy
California Natural Gas Vehicle Coalition	• Natural gas delivery: compressed, liquefied, and biogas • Natural gas vehicles • Natural gas infrastructure
National Biodiesel Board	• Feedstocks • Biodiesel production • Biodiesel infrastructure
Advanced Biofuels Association	• Biofuel production • Investment in biofuels
Environmental Entrepreneurs	• Biofuel production • Investment in biofuels
Ceres	• Alternative fuel investments

2.2. Fuel Volumes, Forecasts, and LCFS Compliance

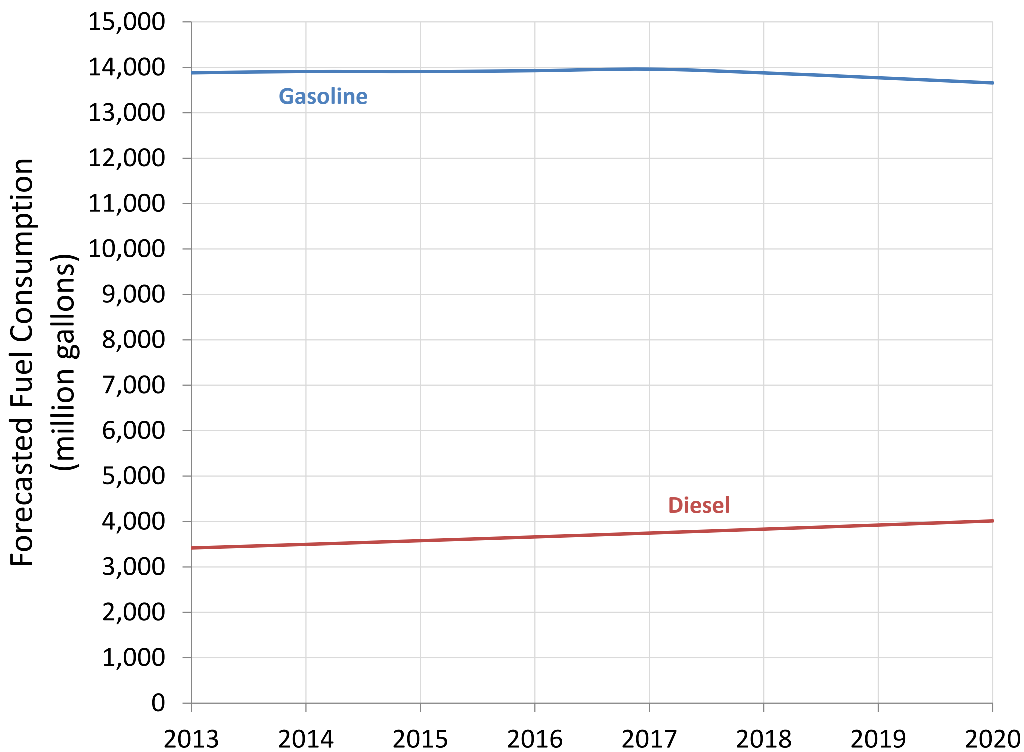
Conventional Fuel Volumes and Forecasts

ICF used a combination of transportation fuel demand forecasts reported by the California Energy Commission (CEC) from the most recent publicly available Integrated Energy Policy Report from 2011[1] and fuel volumes reported to date by regulated parties.[2] The gasoline and

[1] California Energy Commission (CEC). "Transportation Energy Forecasts and Analyses for the 2011 Integrated Energy Policy Report." CEC, August 2011: Available at: http://www.arb.ca.gov/msprog/clean_cars/clean_cars_ab1085/cec-600-2011-007-sd.pdf

diesel demand forecasted trends were applied to actual volumes reported through LCFS reporting from 2011 and 2012. These fuel forecasts account for the most recent fuel economy and GHG tailpipe emission standards for light-, medium-, and heavy-duty vehicles. Although it is likely that there will be additional regulations on medium- and heavy-duty regulations, we only incorporated regulations that have been promulgated into our forecasts.

Exhibit 2. Forecasted Gasoline (blue) and Diesel (red) Consumption in California



Other Regulations Considered in the Analysis

There are many regulations that impact the transportation sector in California. To the extent feasible, ICF accounted for regulatory drivers in the development of LCFS compliance scenarios. Regulatory overlap becomes a more significant issue in the second phase of the project because the attribution of costs associated with LCFS compliance impact the corresponding macroeconomic impacts. This issue is less of a concern in the consideration of LCFS compliance scenarios. Regardless, the following regulatory drivers were considered in the development of LCFS compliance scenarios.

Federal Renewable Fuel Standard (RFS2)

The United States Environmental Protection Agency (EPA) administers the federal Renewable Fuel Standard (RFS2). The RFS2 is a volumetric standard for blending biofuels into the

[2] Yeh, S; Whitcover, J; and Kessler, J. Status Review of California's Low Carbon Fuel Standard, Spring 2013. Available online at: http://tinyurl.com/LCFS-StatusReview2013

transportation fuel mix.[3] Although the RFS2 is a significant driver for biofuel blending nationwide, the regulation does not require a so-called fair-share for California. In other words, because California accounts for about 11 percent of domestic transportation fuel consumption, it would therefore be responsible for the equivalent fair-share of RFS2 obligations. However, regulated parties (e.g., refiners) can in theory comply with the RFS2 without blending biofuels in California. Although regulated parties do comply with the standard by blending biofuels in California, we make the assumption that the RFS2 does not act as a major regulatory driver in California – it plays a role in that it is a complementary regulatory driver for advanced biofuel production. Regulated parties under the LCFS that blend low carbon biofuels will earn credit towards RFS2, however, ICF's analysis assumes that the driver for California consumption is largely the LCFS and not RFS2.

Light Duty Fuel Economy Standards and Tailpipe GHG Standards

Although LCFS focuses on the carbon intensity of transportation fuels, there are other regulatory mechanisms in place in the transportation sector. These other regulations ensure that vehicles are becoming more fuel efficient and that GHG emissions from vehicles are lower. In 2002, California passed AB 1493 (Pavley) which limits light duty vehicle tailpipe GHG emissions. In 2009, the EPA granted California's waiver request, allowing it to regulate vehicle GHG emissions; CARB subsequently adopted amendments to the Pavley standards to reduce light duty tailpipe GHG emissions from new vehicles sold in California from 2009 through 2016. As part of a national agreement with the Obama Administration, agencies, automakers, and other stakeholders, the U.S. Environmental Protection Agency (EPA) and the U.S. National Highway Traffic Safety Administration (NHTSA) issued harmonized GHG and fuel economy standards in partnership with CARB, equivalent to 35.5 mpg by model year 2016.

As part of the AB 32 Scoping Plan, the Plan that describes the approach California will take to reduce GHG emissions to 1990 levels by 2020, CARB began development of the Advanced Clean Cars program. This program is essentially a combination of Low Emission Vehicle III (LEVIII) rulemaking and an update to the Zero Emission Vehicle (ZEV) Program. LEV III reduces tailpipe criteria pollutant and GHG emissions. The GHG portion is referred to as Pavley 2.

The EPA and NHTSA worked in parallel to develop the second phase of the national program, and in 2012 issued new federal light duty GHG and fuel economy standards for model years 2017-2025. EPA's fleet average standard of 163 grams per miles corresponds to 54.5 miles per gallon (mpg) if all reductions are made through fuel economy improvements. As part of the national agreement, CARB allows compliance with the EPA's requirements to serve as compliance with California's standards for those model years.

The light duty fuel economy standards and tailpipe GHG standards were incorporated into gasoline and diesel demand forecasts.

[3] The RFS2 does not include non-biofuels such as electricity, natural gas, or hydrogen. However, the RFS2 does include biogas as an eligible fuel – in a recent proposed rulemaking, the EPA is proposing to amend the biogas pathways to list renewable CNG or LNG as the fuel types and biogas as the feedstock. Furthermore, EPA's recent proposed rulemaking would allow renewable electricity (used in electric vehicles) produced from landfill gas to generate credits under the RFS2. More information is available online at: http://www.epa.gov/otaq/fuels/renewablefuels/documents/nprm-pathways-2-signature-version.pdf

Zero Emission Vehicle Program

ARB adopted the Zero Emission Vehicle (ZEV) Program in 1990 as part of the Low Emission Vehicle (LEV) to reduce criteria pollutant emissions in order to meet health based air quality goals. Today, the ZEV Program requires a certain percentage of light duty vehicles sold in California to be partly or fully zero emitting at the tailpipe. Qualifying technologies include battery electric vehicles (BEVs), plug-in hybrid electric vehicles (PHEVs), and hydrogen fuel cell vehicles (FCVs). ARB recently adopted the changes to the ZEV Program as part of the Advanced Clean Cars Program, with modified requirements over the model year 2014 to 2025 time period. The table below provides annual light duty vehicle sales for ARB's likely compliance scenario. Note that for the purposes of this study, the so-called transitional zero emission vehicles (TZEVs) are all considered plug-in hybrid electric vehicles (PHEVs).

Exhibit 3. Advanced Vehicle Technology Populations, Most Likely Compliance Scenario for the ZEV Program

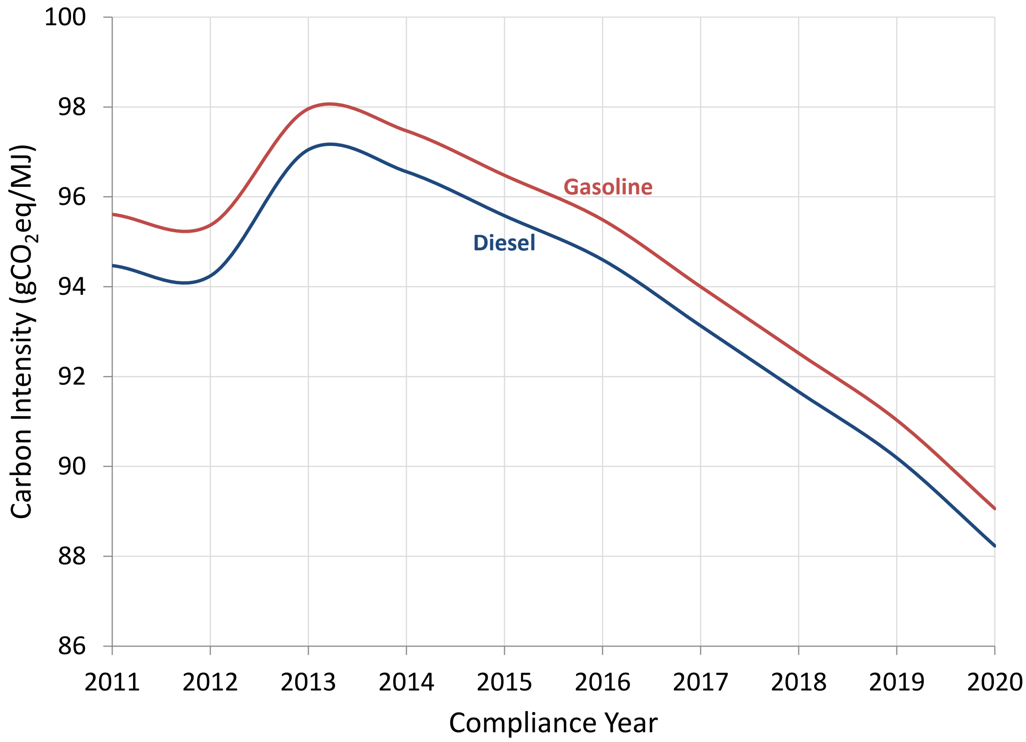
ZEV Type	2017	2018	2019	2020
FCVs	6,337	9,237	15,437	26,037
BEVs	42,832	56,732	84,032	121,732
TZEVs / PHEVs	128,589	189,889	265,189	354,289
Total	177,758	255,858	364,658	502,058

The credits generated by the consumption of electricity and hydrogen in ZEVs to comply with the ZEV Program will generate LCFS credits. ICF considered the credits generated through CARB's most likely compliance scenario as the minimum number of credits for PEVs and FCVs. Any credits generated above and beyond the most likely compliance scenario were attributed to the LCFS and not the ZEV Program.

LCFS Compliance Schedule

The compliance schedule for the LCFS is shown in the figure below.

Exhibit 4. LCFS Compliance Schedule for Gasoline and Diesel



Note that CARB modified the baseline number, which was originally an average of crude oil supplied to California refineries in 2006; the values from 2013 to 2020 reflect the updated average of crude oil supplied to California refineries in 2010.

Note that although there are separate compliance schedules for gasoline and diesel, LCFS credits are fungible across these fuels. For instance, credits generated using a low carbon fuel that substitutes for gasoline can be used to offset deficits generated by diesel. This is an important aspect of LCFS compliance because, based on ICF's research and analysis, there is considerable room for over-compliance in the diesel sector compared to the gasoline sector. There are two prominent reasons for this:

- Firstly, ethanol is already blended into gasoline at a rate of 10 percent by volume. The primary pathway for compliance in the near-term future for gasoline suppliers is simply to blend ethanol from feedstocks with a lower carbon intensity. However, they are blending the same volume of ethanol.
- Secondly, there is very little biodiesel consumed in California today (less than 1 percent by volume in 2010). Biodiesel blends of up to 5 percent (B5) are considered identical to conventional diesel according to the ASTM International. ASTM International is the leading standard-setting organization for fuel in North America and sets science-based standards by consensus of fuel producers, petroleum distributors, original equipment manufacturers, and regulators. As a result, not only can diesel providers blend low carbon biodiesel, they can drastically increase the volume of biodiesel blended and earn credits for those reductions.

2.3. Compliance Options Considered

ICF considered a variety of low carbon fuels to develop representative LCFS compliance scenarios. Furthermore, to determine the balance of deficits and credits in each compliance scenario, ICF made various assumptions regarding how vehicles and fuels will be used in the near-term future towards LCFS compliance. These are distinguished between fuels that substitute for gasoline (the gasoline pool) and fuels that substitute for diesel.

Fuels that Substitute for Gasoline

ICF assumed that ethanol would continue to be blended into gasoline at a rate of 10 percent by volume, consistent with today's reformulated gasoline requirements. ICF limited the blending of ethanol with gasoline at a maximum of 15 percent by volume based on EPA's recently issued waiver for E15 in vehicle model years (MY) 2001 or newer. Although there is no E15 consumed in California today – and very little generally in the United States – ICF anticipates that E15 will be consumed in meaningful quantities in California in the 2017-2018 timeframe as a result of drivers such as LCFS and the RFS2.

ICF considered the following feedstocks for ethanol production:

- **Corn, Conventional**: Corn from conventional processes is typically sourced from the Midwest. Corn has been and continues to be the most common feedstock for ethanol consumed in California. Nearly 1.5 billion gallons of corn ethanol are consumed in California today as an oxygenator in reformulated gasoline.
- **Corn, California-produced**: California currently has seven (7) ethanol production facilities with a combined nameplate production capacity of more than 250 million gallons; however, actual production capacity is close to 200 million gallons annually. For the purposes of this report, we assume that there is potential for modest expansion in California facilities, with a maximum capacity of 220 million gallons. We assumed modest improvements consistent with information provided via consultation with Pacific Ethanol.
- **Corn, low carbon intensity**: There is significant potential to lower the carbon intensity of corn ethanol through a variety of measures. For the purposes of this report, ICF assumed a lower limit of 73 g/MJ for what we term low carbon intensity corn ethanol. There has already been a shift towards more efficient corn ethanol production as a result of the LCFS, with many new lower carbon pathways submitted to and approved by CARB.
- **Sugarcane**: Most sugarcane ethanol is produced in Brazil and shipped via tanker to the United States. In some cases, hydrous ethanol is shipped to a country in the Caribbean Basin Initiative (CBI); the excess water is subsequently removed and the anhydrous ethanol is shipped to the US. This step was more common when the US had a tariff on sugarcane ethanol imported directly from Brazil; the interim step allowed importers to avoid paying the tariff. The ethanol arrives in California in two ways: 1) directly via port or 2) via rail after landing in Texas. For the sake of reference, the United States imported 500 million gallons of sugarcane ethanol in 2012, with an estimated 90 million gallons coming to California.
- **Cellulosic**: Cellulosic ethanol refers generally to ethanol produced from wood, grasses, or other lignocelluosic materials. For the purposes of this report, ICF did not identify feedstocks specifically; rather, we focused on the long-term likelihood (out to 2020) of cellulosic ethanol production and the availability to California.

Although ethanol from various feedstocks is the primary substitute for gasoline today, ICF also considered the following fuels that substitute for gasoline:

- **Renewable gasoline** is a drop-in replacement biofuel for gasoline. To remain conservative in our estimates, ICF assumed that 50% of Energy Information Administration (EIA)-forecasted renewable gasoline production will be available to California, starting in 2015.
- **Electricity** used in plug -in electric vehicles (PEVs), including plug-in hybrid electric vehicles (PHEVs) and battery electric vehicles (BEVs), stands to play an important role towards LCFS compliance, particularly in later years of the regulation as California's Zero Emission Vehicle (ZEV) Program takes full effect. In each of the compliance scenarios, a minimum number of PEVs was deployed to be consistent with CARB' most likely scenario. ICF also considered the potential for a more rapid expansion of the market for PEVs.
- **Hydrogen** consumed in fuel cell vehicles (FCVs) is another aspect of California's ZEV Program that was also considered. Similarly, ICF deployed a minimum number of FCVs using hydrogen to be consistent with CARB's most likely compliance scenario. ICF also considered the potential for a more rapid expansion of the market for FCVs.
- **Natural gas** has significant potential to displace gasoline consumption in medium-duty and light heavy-duty vehicles.

The table below shows the carbon intensity values used for fuels that substitute for gasoline. In most cases, we employed static carbon intensity values; however, in some cases we did decrease the carbon intensity of a transportation fuel to reflect expected advanced in technologies. Unless otherwise noted, the carbon intensity values were taken directly from CARB's look-up tables.

Exhibit 5. Carbon Intensity Values for Fuels that Substitute for Gasoline

Fuel / Feedstock	Carbon Intensity (gCO2e/MJ)
Ethanol, conventional	95.66
Ethanol, CA corn	80.70; decreasing to 70.70 in 2016
Ethanol, Low CI Corn	73.21
Ethanol, Sugarcane	73.40; decreasing to 67.38 by 2020
Ethanol, Cellulosic	21.30 [a]
Renewable Gasoline	25.00 [b]
Compressed natural gas	68.00
Biogas, landfill	11.56
Electricity, marginal [c]	30.80; decreasing to 26.32 by 2020
Hydrogen [d]	39.42

[a] The average of CARB pathways for ethanol from farmed trees and forest ways
[b] Estimated carbon intensity based on stakeholder consultation.
[c] Includes the energy economy ratio (EER) of 3.4 for electric vehicles
[d] Includes the EER of 2.5 for fuel cell vehicles

Fuels that Substitute for Diesel

The fuel volumes in the compliance scenarios represent a combination of ICF research and input provided by the National Biodiesel Board (NBB), with similar biodiesel blending rates and feedstocks: In the development of the compliance scenarios, we considered the following feedstocks for biodiesel:

- **Soybean oil**: Soybean oil is the largest single feedstock for biodiesel production in the United States. It is a well-established crop with a robust commodity market. While most soybeans are grown in the Midwest and a significant amount of biodiesel production capacity exists in the Midwest, soybean oil is also transported to independent biodiesel production facilities in California and elsewhere.
- **Waste grease**: Waste grease is significant feedstock at California production facilities. As a waste feedstock, waste grease has a low carbon intensity. The production process for biodiesel from waste grease is generally more energy intensive than for vegetable oils because there is generally a higher free fatty acid content. This requires an additional acid-catalyzed esterification reaction, thereby increasing the energy inputs.
- **Animal fats**: Animal fats, like waste grease, are also a significant feedstock for biodiesel production and yield a finished product with a low carbon intensity. Typically, animal fats include poultry, tallow, and white grease (or lard).
- **Corn oil**: Corn oil is a byproduct of corn ethanol production and generally requires retrofitting an ethanol plant. It is a feedstock with significant growth potential for the biodiesel industry. Corn oil extraction is a relatively new commodity for the majority of ethanol production facilities, but represents another high-value co-product. Anecdotal evidence indicates that the majority of corn ethanol facilities in the US will have installed equipment to extract corn oil by the end of 2013.
- **Canola oil**: Canola oil is similar to soybean oil as a feedstock; it is more prominent feedstock in the European Union (referred to there as rapeseed). In North America, canola production historically exists primarily in Canada and northern states of the US. It is increasingly being planted as a winter crop is places like Oklahoma and the Carolinas. Existing transportation infrastructure makes Canola a significant feedstock for biodiesel production on the West Coast.

ICF also considered the following alternative fuels:

- **Renewable diesel**: Like biodiesel, there are multiple feedstocks that can be used to produce renewable diesel, including palm oil, canola (or rapeseed) oil, jatropha oil, camelina oil, soy oil, waste greases, and animal fats (i.e., tallow). ICF considered renewable diesel produced from tallow; this pathway is largely based on the availability of renewable diesel produced by Neste Oil in its Singapore production plant using its renewable diesel production process.
- **Natural gas**: ICF considered the potential for natural gas – compressed, liquefied, and biogas – in heavy-duty applications such as short-, medium-, and long-haul trucks, refuse haulers, and transit buses. For the purposes of this report, and after consultation with the California Natural Gas Vehicle Coalition, we assumed that about 85 percent of natural gas in the heavy-duty sector (Class 7 and Class 8 trucks) will be consumed as LNG in spark-ignited engines and 15 percent will be consumed as CNG in spark-ignited engines for medium-heavy and heavy-heavy duty vehicles.

- **Electricity**: Electricity used in fixed guideway applications (e.g., light- and heavy-rail) and forklifts were considered in the analysis, and are discussed in more detail in Section 4.7. Although BEVs and PHEVs have the potential to displace diesel in the medium- and heavy-duty sector, ICF limited the scope of our analysis regarding electric vehicles to light-duty applications.

The table below includes the carbon intensity values used to determine the balance of LCFS deficits and credits in each scenario. Unless otherwise noted, the carbon intensity values were taken directly from CARB's look-up tables.

Exhibit 6. Carbon Intensity Values for Fuels that Substitute for Diesel

Fuel / Feedstock	Carbon Intensity (gCO2e/MJ)
Biodiesel, soy oil	83.25
Biodiesel, waste grease	13.80
Biodiesel, corn oil	4.00
Biodiesel, canola oil [a]	83.25
Renewable diesel, tallow	19.65
Compressed natural gas [b]	75.56
Liquefied natural gas [c]	77.76
Biogas, landfill [b]	12.51

[a] Biodiesel from canola oil is not in the LCFS look-up tables. ICF used a conservative value equivalent to biodiesel from soy oil.

[b] Includes the EER of 0.9 for spark ignition CNG vehicles

[c] Average of LNG pathways with natural gas liquefied in California with 80% and 90% efficiency.

3. Overview of Compliance Scenarios

From a broad perspective, there are two ways to deploy alternative fuels that will help comply with the LCFS. Firstly, biofuels can be blended into conventional gasoline or diesel for consumption in the existing vehicle fleet. Secondly, advanced vehicle technologies can be deployed, which consume alternative fuels such as natural gas, electricity, or hydrogen. ICF maintains that compliance with the LCFS will require a diverse mix of all of these alternative fuels. Due to constraints on how quickly the vehicle fleet can be turned over, however, biofuel blending is and will likely continue to be a major form of LCFS compliance until advanced vehicle technologies are deployed in higher numbers. The scenarios outlined in the following sections highlight the diversity of alternative fuels that are available or forecasted to be available out to 2020.

ICF developed two compliance scenarios in coordination with the Stakeholder Review Panel. As noted above, both scenarios have significant reliance on biofuel blending to achieve compliance – using a mix of so-called first generation biofuels and advanced biofuels, with an emphasis on fuels that we know are available today. Scenario 1, however, reflects a market that is more dependent on advanced vehicle technologies than Scenario 2, thereby decreasing the pressure on biofuel blending.

The Stakeholder Review Panel developed a third compliance scenario, referred to as the LCFS Enhanced Scenario. This scenario has even greater advanced vehicle penetrations than Scenario 1, and includes additional credits generated from off-road electrification and innovative crude extraction processes.

The table below characterizes broadly the scenarios with more detail in the subsequent sections.

Exhibit 7. Overview of LCFS Compliance Scenarios Developed

Scenario	Ethanol	Biodiesel / Renewable Diesel	Natural Gas	Advanced Vehicles (PEVs / FCVs)	Other
Scenario 1	Maintained E10 blend rate until 2018 E15 introduced 2019 and 2020 Cellulosic/advanced biofuels capped at 50% of volumes reported by E2	Limited blend percentages to 20 percent by volume of conventional diesel.	Linear increase from 2012 to 2020 to 1.2 billion gge 10% biogas Based on estimates from CNGVC	220,000 BEVs; 800,000 PHEVs; and 110,000 FCVs in 2020	Only forklifts and rail with no additional credits for displacement
Scenario 2	Maintained E10 blend rate until 2017 E15 introduced 2018-2020 Cellulosic/advanced biofuels capped at 13% of volumes reported by E2	Limited blend percentages to 20 percent by volume of conventional diesel. Increased corn oil BD Increased RD from tallow in 2018-2020	Linear increase from 2012 to 2020 to 900 million gge, 10% biogas Based on estimates from CNGVC	ZEV Program Compliance	Only forklifts and rail with no additional credits for displacement
LCFS Enhanced	Maintained E10 blend rate Brazilian sugarcane capped at less than 350 MGY until 2018	Limited blend percentages to 20 percent by volume of conventional diesel.	Linear increase from 2012 to 2020 to 1.5 billion gge 10% biogas Based on estimates from CNGVC	240,000 BEVs; 960,000 PHEVs; and 110,000 FCVs in 2020	Marginal incremental calculations for forklifts and rail, no displacement when including ports, small non-truck and truck related
Assumption for all Scenarios	Maximum ethanol is E15 FFVs driving 85% of miles on E85. Maximums for ethanol: • Low CI corn at 1 BGPY • Sugarcane at 500 MGPY			40% PHEV VMT is electric	Compliance achieved in 2011 and 2012 Assumed 1 million banked credits at end of 2012

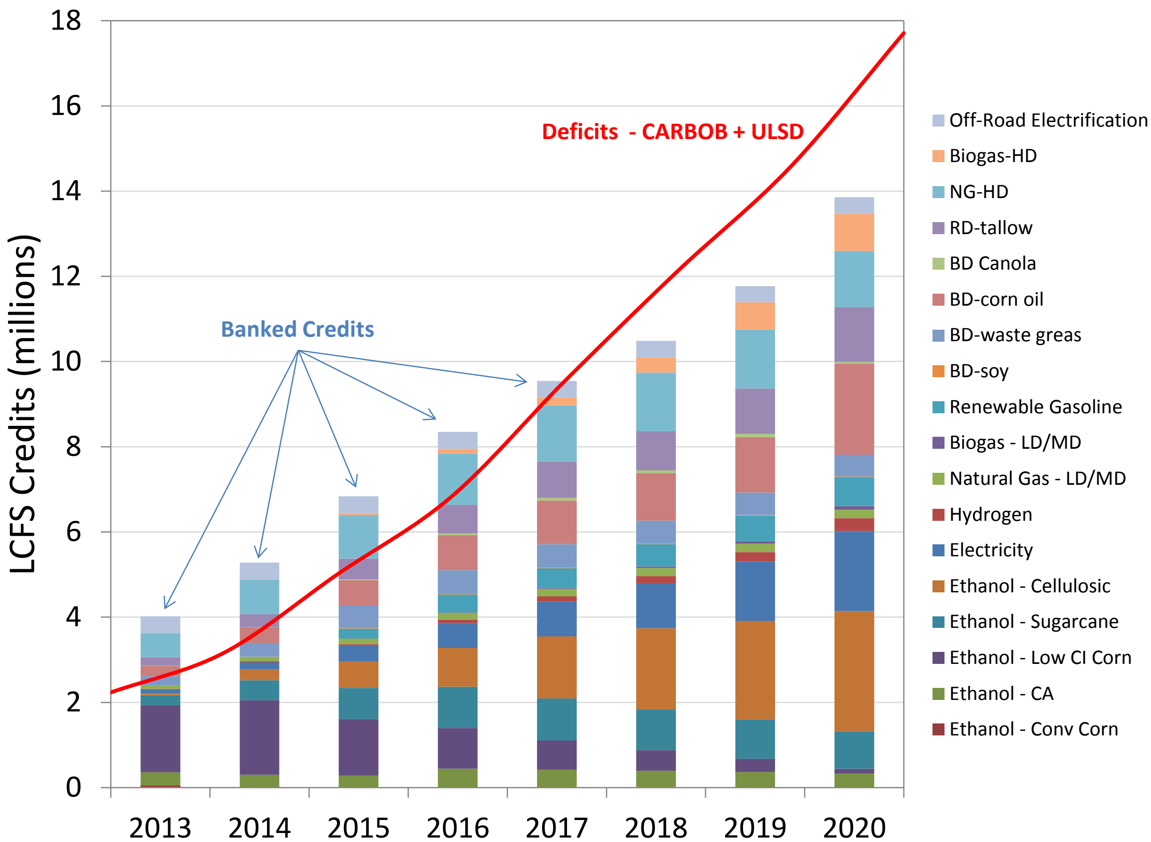
* gge = gasoline gallon equivalent

3.1. Compliance Scenario 1

Summary Overview of Compliance Scenario 1

Exhibit 8 shows the annual balance of credits and deficits (in millions) for Scenario 1. Each colored stacked bar represents credits generated via low carbon fuels; the red line represents the deficits from forecasted CARBOB and ultra low sulfur diesel (ULSD) consumption. When the stacked bars are above the red line (2013-2017) that indicates a year in which more credits are generated than are required to meet compliance. Conversely, in years where the stacked bars are lower than the red line (2018-2020) that indicates a year in which banked credits must be used. The stacked bars are grouped according to the fuel being displaced. The stacked bars at the bottom of the graph are for fuels that displace gasoline; moving up the graph, the stacked bars represent fuels that displace diesel.

Exhibit 8. Balance of LCFS Credits and Deficits in Scenario 1



The table below highlights the deficits generated by forecasted CARBOB and diesel consumption (in millions of deficits) compared to the credits generated by fuels that substitute for gasoline and diesel, respectively. The last two rows of the table show the balance of credits and the number of credits banked after compliance. Note that there is significant over-compliance in the early years of the program. Furthermore, note that although diesel accounts for only about 20 percent of deficits, the fuels that substitute for diesel account for about 45 percent of credits.

Exhibit 9. LCFS Credits and Deficits: Banking in Scenario 1

Fuel		2013	2014	2015	2016	2017	2018	2019	2020
Deficits (millions)	CARBOB	-1.82	-2.55	-4.00	-5.44	-7.62	-9.69	-11.67	-14.24
	ULSD	-0.42	-0.62	-1.01	-1.37	-1.90	-2.43	-2.90	-3.47
Credits (millions)	Gasoline Subs	2.39	3.06	3.73	4.53	5.15	5.72	6.38	7.28
	Diesel Subs	1.63	2.22	3.11	3.81	4.39	4.77	5.39	6.57
	Balance	1.79	2.12	1.83	1.53	0.02	-1.63	-2.80	-3.85
	Banked (Net)	2.79	4.90	6.74	8.27	8.29	6.66	3.86	0.01

Note: The banked balance in 2013 includes one million credits from over-compliance in 2011-2012

Ethanol and Biofuels that Substitute for Gasoline

ICF considered ethanol from the aforementioned feedstocks: corn (with varying production locations and processes), sugarcane, and cellulosic. The table below indicates the volumes (in million gallons) of ethanol broken down by feedstock in Scenario 1.

Exhibit 10. Ethanol Volumes (in million gallons) in Scenario 1

Feedstock	2013	2014	2015	2016	2017	2018	2019	2020
Corn, Conventional	264	0	0	0	0	0	0	0
California Corn	215	220	220	220	220	220	220	220
Low CI Corn	780	884	699	526	408	311	214	87
Sugarcane	120	240	360	480	500	500	500	500
Cellulosic	5	41	100	150	246	328	406	511
Total	1,384	1,385	1,379	1,376	1,374	1,359	1,340	1,318
% EtOH in Gasoline	10%	10%	10%	10%	10%	10%	10%	10%

Biodiesel

The table below shows the volume of biodiesel (by feedstock) consumed in Scenario 1.

Exhibit 11. Biodiesel Consumption in Scenario 1 (million gallons)

Feedstock	2013	2014	2015	2016	2017	2018	2019	2020
Soy Oil	3	5	8	11	14	16	19	23
Waste Grease	19	29	48	51	51	51	51	51
Corn Oil	19	29	48	67	86	95	112	189
Canola Oil	3	5	8	27	49	59	80	62
BD, Total	45	68	113	157	200	221	262	325
Biodiesel Blend (%)	1%	2%	4%	5%	7%	8%	10%	12%

Renewable Diesel

The table below shows the volume of renewable diesel consumed in Scenario 1.

Exhibit 12. Renewable Diesel Consumption in Scenario 1 (million gallons)

Feedstock	2013	2014	2015	2016	2017	2018	2019	2020
Tallow	19	29	48	67	86	95	112	139

Natural Gas

The consumption of natural gas is the medium-level of deployment from the CNGVC's estimates and reaches 1,200 million gasoline gallon equivalents (gge) consumed in 2020, as shown in the table below.

Exhibit 13. Natural Gas Consumption in Scenario 1 (million gge)

	2013	2014	2015	2016	2017	2018	2019	2020
NG, medium-duty	20	30	40	49	58	67	74	81
Biogas, medium-duty	-	-	0	1	2	4	6	9
NG, heavy-duty	250	373	491	606	719	821	908	999
Biogas, heavy-duty	-	-	5	12	22	43	79	111
Total	271	403	536	669	802	934	1,067	1,200

Advanced Vehicle Technologies: PEVs and FCVs

Advanced vehicle technologies were deployed at an accelerated rate in Compliance Scenario 1 relative to the minimum level of deployment to comply with the ZEV Program. The table below shows the consumption of hydrogen in FCVs and electricity in PEVs in gasoline equivalent volumes.

Exhibit 14. Hydrogen and Electricity Consumption in ZEVs in Scenario 1 (million gge)

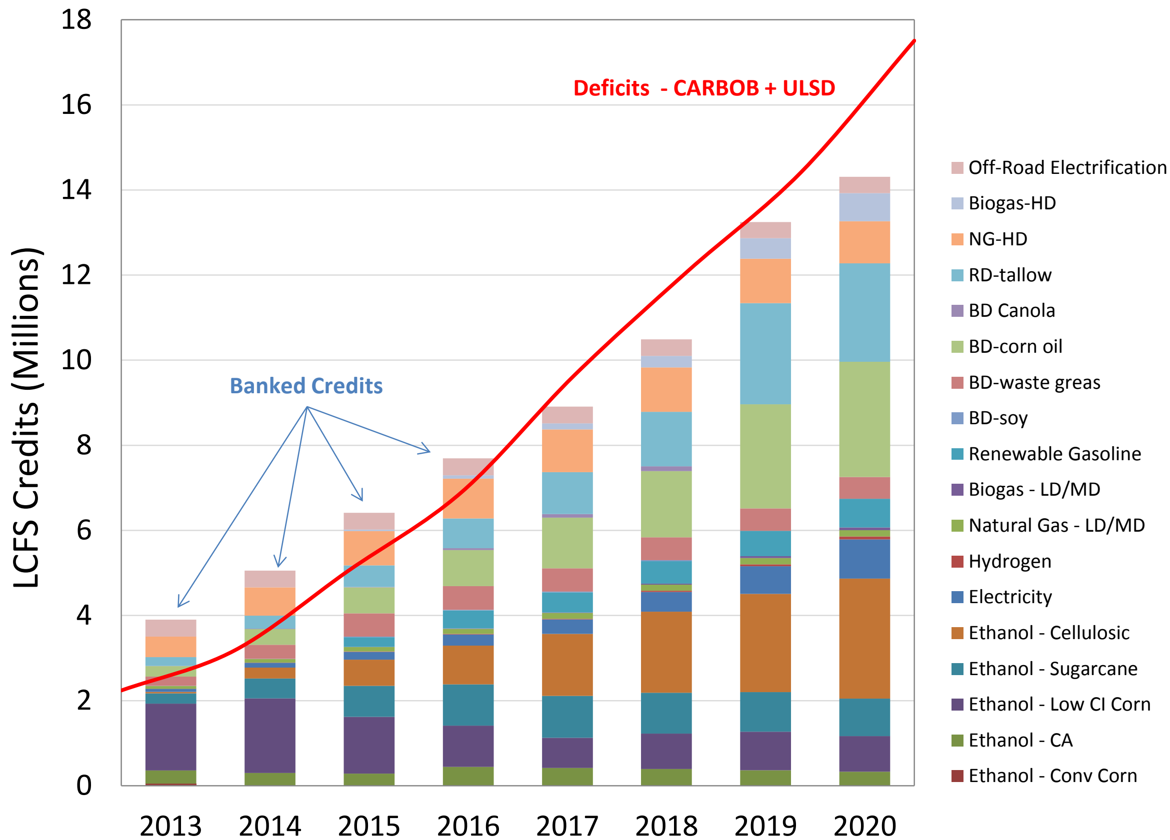
Vehicle	2013	2014	2015	2016	2017	2018	2019	2020
FCVs	0	1	2	5	8	11	15	21
BEVs	4	6	14	23	32	43	58	76
PHEVs	10	16	34	50	69	87	119	153
Total	14	24	51	78	109	141	192	251

3.2. Compliance Scenario 2

Summary Overview of Compliance Scenario 2

Exhibit 15 shows the annual balance of credits and deficits (in millions) for Scenario 1. Each colored stacked bar represents credits generated via low carbon fuels; the red line represents the deficits from forecasted CARBOB and ULSD consumption. When the stacked bars are above the red line (2013-2016) that indicates a year in which more credits are generated than are required to meet compliance. Conversely, in years where the stacked bars are lower than the red line (2017-2020) that indicates a year in which banked credits must be used. The stacked bars are grouped according to the fuel being displaced. The stacked bars at the bottom of the graph are for fuels that displace gasoline; moving up the graph, the stacked bars represent fuels that displace diesel.

Exhibit 15. Balance of Credits and Deficits for Compliance Scenario 2



The table below highlights the deficits generated by forecasted CARBOB and diesel consumption (in millions of deficits) compared to the credits generated by fuels that substitute for gasoline and diesel, respectively. The last two rows of the table show the balance of credits and the number of credits banked after compliance. Note that there is significant over-compliance in the early years of the program. Furthermore, note that although diesel accounts for only about 20 percent of deficits, the fuels that substitute for diesel account for about 50 percent of credits.

Exhibit 16. LCFS Credits and Deficits: Banking in Scenario 2

Fuel		2013	2014	2015	2016	2017	2018	2019	2020
Deficits (millions)	CARBOB	-1.82	-2.55	-4.01	-5.47	-7.69	-9.63	-11.46	-13.85
	ULSD	-0.42	-0.63	-1.03	-1.42	-1.96	-2.47	-2.96	-3.66
Credits (millions)	Gasoline Subs	2.34	2.98	3.49	4.12	4.54	5.28	5.99	6.75
	Diesel Subs	1.56	2.08	2.92	3.58	4.36	5.21	7.25	7.56
	Balance	1.66	1.88	1.37	0.81	-0.74	-1.60	-1.17	-3.20
	Banked (Net)	2.66	4.54	5.91	6.72	5.98	4.37	3.20	0.01

Note: The banked balance in 2013 includes one million credits from over-compliance in 2011-2012

Ethanol and Biofuels that Substitute for Gasoline

The volumes of ethanol (in million gallons) consumed in Scenario 2 are shown in the table below.

Exhibit 17. Ethanol Volumes (in million gallons) in Scenario 2

Feedstock	2013	2014	2015	2016	2017	2018	2019	2020
Corn, Conventional	240	0	0	0	0	0	0	0
California	220	220	220	220	220	220	220	220
Low CI Corn	780	845	644	514	419	532	640	580
Sugarcane	140	280	420	500	500	500	500	500
Cellulosic	5	41	100	150	246	328	406	511
Total	1,385	1,386	1,384	1,384	1,385	1,580	1,766	1,811
% EtOH in Gasoline	10%	10%	10%	10%	10%	11.5%	13.0%	13.5%

Biodiesel

The table below shows the volume of biodiesel and renewable diesel (by feedstock) consumed in Scenario 2.

Exhibit 18. Biodiesel and Renewable Diesel Consumption in Scenario 2 (million gallons)

Feedstock	2013	2014	2015	2016	2017	2018	2019	2020
Soy Oil	3	5	8	12	17	22	0	0
Waste Grease	20	30	49	51	51	51	51	51
Corn Oil	20	30	50	71	101	135	211	239
Canola Oil	3	4	7	29	63	100	0	0
BD, Total	46	69	115	162	232	308	262	290
Biodiesel Blend (%)	1%	2%	4%	5%	8%	11%	9%	10%

Renewable Diesel

The table below shows the volume of renewable diesel consumed in Scenario 2.

Exhibit 19. Renewable Diesel Consumption in Scenario 2 (million gallons)

Feedstock	2013	2014	2015	2016	2017	2018	2019	2020
Tallow	20	30	49	69	99	132	251	251

Natural Gas

The deployment of natural gas is the least aggressive in Scenario 2 and reaches 900 million gge consumed in 2020, as shown in the table below.

Exhibit 20. Natural Gas Consumption in Scenario 2 (million gge)

	2013	2014	2015	2016	2017	2018	2019	2020
NG, medium-duty	17	25	31	38	45	51	56	61
Biogas, medium-duty	-	-	0	1	1	3	5	7
NG, heavy-duty	216	304	388	470	551	623	685	749
Biogas, heavy-duty	-	-	4	10	17	33	60	83
Total	233	328	424	519	614	709	805	900

Advanced Vehicle Technologies: PEVs and FCVs

Advanced vehicle technologies were deployed at minimum ZEV compliance in Scenario 2; the table below shows the consumption of hydrogen in FCVs and electricity in PEVs in gasoline equivalent volumes.

Exhibit 21. Hydrogen and Electricity Consumption in ZEVs in Scenario 2 (million gge)

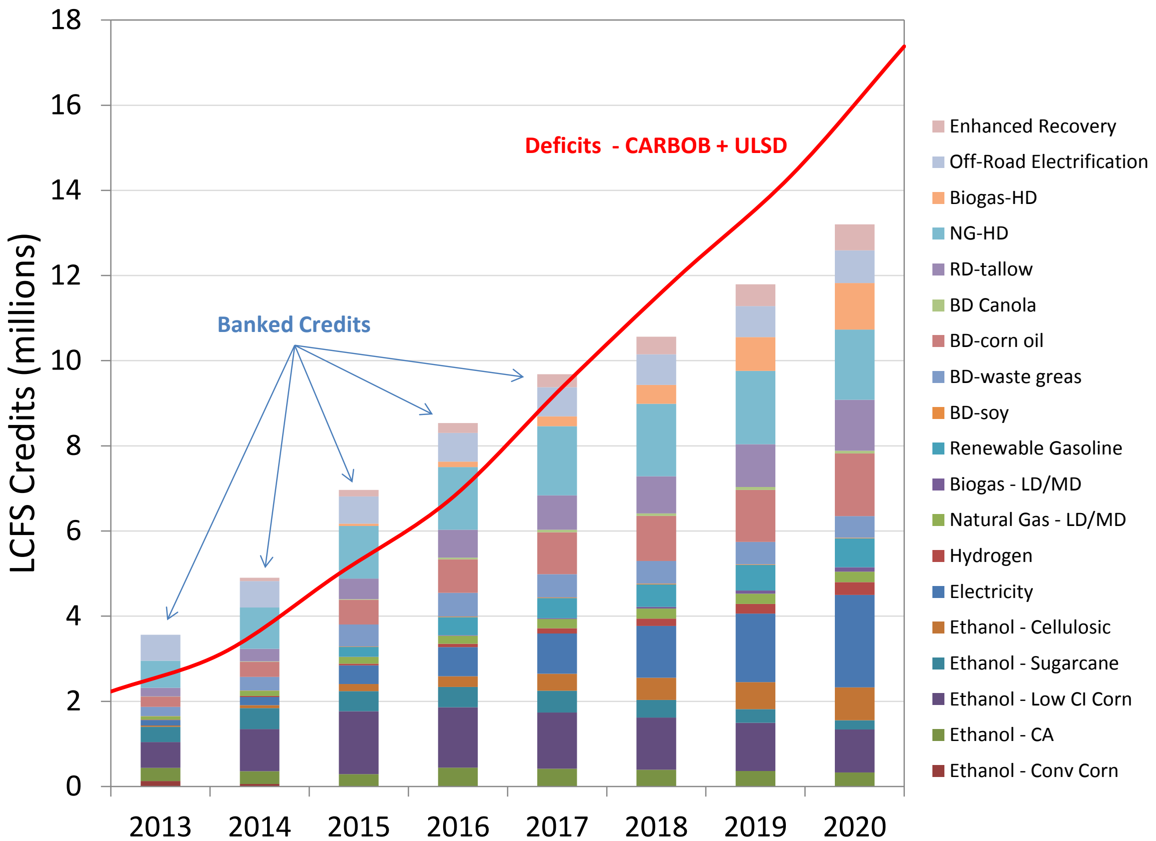
Vehicle	2013	2014	2015	2016	2017	2018	2019	2020
FCVs	0	0	1	1	1	2	3	5
BEVs	3	4	7	10	13	19	27	37
PHEVs	7	10	15	20	25	36	51	68
Total Adv Vehicles	10	14	23	31	39	57	81	110

3.3. LCFS Enhanced Scenario

Summary Overview of LCFS Enhanced Compliance Scenario

Exhibit 22 shows the annual balance of credits and deficits (in millions) for the LCFS Enhanced Scenario. Each colored stacked bar represents credits generated via low carbon fuels; the red line represents the deficits from forecasted CARBOB and ULSD consumption. When the stacked bars are above the red line (2013-2017) that indicates a year in which more credits are generated than are required to meet compliance. Conversely, in years where the stacked bars are lower than the red line (2018-2020) that indicates a year in which banked credits must be used. The stacked bars are grouped according to the fuel being displaced. The stacked bars at the bottom of the graph are for fuels that displace gasoline; moving up the graph, the stacked bars represent fuels that displace diesel. Note that the top stacked bar, labeled Enhanced Recovery, includes credits generated by deploying innovative crude recovery technologies. These technologies reduce the carbon intensity of both gasoline and diesel, and are discussed in more detail below.

Exhibit 22. Balance of Credits and Deficits in the LCFS Enhanced Scenario



The table below highlights the deficits generated by forecasted CARBOB and diesel consumption (in millions of deficits) compared to the credits generated by fuels that substitute for gasoline and diesel, respectively. The last two rows of the table show the balance of credits and the number of credits banked after compliance. Note that there is significant over-compliance in the early years of the program. Furthermore, note that although diesel accounts for only about 20 percent of deficits, the fuels that substitute for diesel account for about 50 percent of credits.

Exhibit 23. LCFS Credits and Deficits: Banking in the LCFS Enhanced Scenario

Fuel		2013	2014	2015	2016	2017	2018	2019	2020
Deficits (millions)	CARBOB	-1.82	-2.54	-3.99	-5.43	-7.60	-9.65	-11.62	-14.15
	ULSD	-0.41	-0.61	-0.98	-1.33	-1.82	-2.30	-2.72	-3.23
Credits (millions)	Gasoline Subs	1.65	2.32	3.43	4.20	4.73	5.16	5.71	6.44
	Diesel Subs	1.92	2.58	3.54	4.33	4.95	5.41	6.08	6.76
	Balance	1.33	1.75	1.99	1.78	0.26	-1.39	-2.55	-4.18
	Banked (Net)	2.33	4.08	6.07	7.86	8.12	6.72	4.18	0.00

Note: The banked balance in 2013 includes one million credits from over-compliance in 2011-2012

Ethanol and Biofuels that Substitute for Gasoline

In the LCFS Enhanced Scenario, cellulosic ethanol was restricted to one quarter of the Scenario 1 and Scenario 2 (or 1/8th of E2's estimated cellulosic ethanol availability). The table below shows the volumes of ethanol consumed in the LCFS Enhanced Scenario.

Exhibit 24. Ethanol Volumes (in million gallons) in the LCFS Enhanced Scenario

Feedstock	2013	2014	2015	2016	2017	2018	2019	2020
Midwest Corn	678	402	100	67	0	0	0	0
California Corn	220	220	220	220	220	220	220	220
Low CI Corn	300	500	780	780	780	780	780	780
Sugarcane	180	250	250	265	302	264	222	170
Cellulosic	5	11	28	41	68	90	111	140
Total	1,383	1,383	1,377	1,373	1,370	1,354	1,333	1,310
% EtOH in Gasoline	10%	10%	10%	10%	10%	10%	10%	10%

Biodiesel

The table below shows the volume of biodiesel (by feedstock) consumed in the LCFS Enhanced Scenario.

Exhibit 25. Biodiesel Consumption in the LCFS Enhanced Scenario (million gallons)

Feedstock	2013	2014	2015	2016	2017	2018	2019	2020
Soy Oil	3	5	8	11	14	15	18	22
Waste Grease	19	29	47	51	51	51	51	51
Corn Oil	19	29	47	65	82	90	106	130
Canola Oil	3	5	8	25	45	54	72	100
BD , Total	45	67	110	151	191	209	247	303
Biodiesel Blend (%)	1%	2%	4%	5%	7%	8%	10%	12%

Renewable Diesel

The table below shows the volume of renewable diesel consumed in the LCFS Enhanced Scenario.

Exhibit 26. Renewable Diesel Consumption in Scenario 2 (million gallons)

Feedstock	2013	2014	2015	2016	2017	2018	2019	2020
Tallow	19	29	47	65	82	90	106	130

Natural Gas

The deployment of natural gas is the most aggressive in the LCFS Enhanced Scenario and reaches 1,500 million gge consumed in 2020, as shown in the table below.

Exhibit 27. Natural Gas Consumption in the LCFS Enhanced Scenario (million gge)

	2013	2014	2015	2016	2017	2018	2019	2020
CNG, medium-duty	23	36	48	60	72	83	92	101
Biogas, medium-duty	-	-	0	1	2	4	8	11
CNG, heavy-duty	285	443	594	742	888	1,019	1,132	1,249
Biogas, heavy-duty	-	-	6	15	27	54	98	139
Total	308	478	649	819	989	1,159	1,330	1,500

Advanced Vehicle Technologies: PEVs and FCVs

Advanced vehicle technologies were deployed assuming aggressive adoption in the LCFS Enhanced Scenario; the table below shows the consumption of hydrogen in FCVs and electricity in PEVs in gasoline equivalent volumes.

Exhibit 28. Hydrogen and Electricity Consumption in ZEVs in the LCFS Enhanced Scenario (million gge)

Vehicle	2013	2014	2015	2016	2017	2018	2019	2020
FCVs	1	1	2	5	8	11	15	21
BEVs	5	7	17	26	37	49	67	88
PHEVs	12	19	41	60	82	104	143	184
Total Adv Vehicles	18	28	61	92	127	165	225	293

Additional Credit-Generating Measures

For the LCFS Enhanced Scenario, additional LCFS credits were calculated for off-road electrification from forklifts and rail for marginal electricity from 2010 consumption. The marginal electricity credits were calculated using the ARB formula which includes diesel displacement. Scenarios 1 and 2 calculated all rail and forklift electricity without diesel displacement. Also, the LCFS enhanced scenario includes additional off-road LCFS credits from ports, small non-road, and truck related applications. These credits were calculated using the base formula which does not include diesel displacement.

ICF also considered LCFS credits that can be earned for purchasing crudes produced using innovative recovery methods, including renewable energy in steam used for extraction and carbon capture and storage.

The table below shows the annual number of credits generated in these two measures.

Exhibit 29. LCFS Credits Earned Through Off-Road Electrification and Innovative Crude Recovery Technologies

	2013	2014	2015	2016	2017	2018	2019	2020
Off-Road Electrification	609,380	624,368	641,487	677,025	684,570	719,512	726,821	765,276
Recovery credits	--	76,778	153,555	230,333	307,110	409,481	511,851	614,221

4. Alternative Fuels Market Assessment

The following subsections include more detailed market research and analysis considered in the development of LCFS compliance scenarios.

4.1. Ethanol

Low carbon intensity corn ethanol

The ethanol industry has already responded to the LCFS by investing in technologies that reduce the carbon intensity of products. Corn ethanol producers have submitted to CARB more than two dozen pathway documents for approval, each of which includes distinctive production processes that help achieve a lower carbon intensity score, including:

- Transition to wet distiller grains. Facilities that have wet distiller grains generally have a carbon intensity score nearly 7 g/MJ lower than for facilities that dry their distiller grains.
- Transition to natural gas. Facilities are seeking to displace energy produced from higher carbon sources by transitioning to natural gas. Similarly, some facilities are seeking to use biogas or biomass for on-site energy consumption.
- Cogeneration. Production facilities are increasingly seeking to use cogeneration at production facilities.
- Feedstock switching. Several corn ethanol producers are adding sorghum or milo to their production facilities to help lower the carbon intensity of ethanol produced. Other facilities have applied for approval of pathways that include wheat slurry.

California represents at least 10 percent of domestic gasoline consumption; with such a sizeable market share, and with LCFS-driven price premium, there is a significant incentive for ethanol producers to continue seeking innovative production processes and technologies that reduce their carbon intensity score. Furthermore, given the uncertainty associated with the availability of lower carbon biofuels e.g., from cellulosic feedstocks, regulated parties will seek out cost-effective reductions from corn ethanol producers where available in the near-term future.

California Corn Ethanol

The California ethanol industry has responded to the LCFS by seeking to reduce their carbon intensity significantly. Most California ethanol today is sold at a carbon intensity of around 80 g/MJ; while interviews with California ethanol producers indicate that they seek to reduce the carbon intensity of their products to 70 g/MJ over the next 3-4 years. There is good reason to believe that the LCFS will continue to drive innovation in California's ethanol production; and given the current carbon intensity of the fuel provided, ICF expects California's ethanol facilities to continue supply the domestic market at near-maximum capacity of around 200 million gallons.

For the purposes of this analysis, California ethanol volumes are reported as corn ethanol; however, there is potential for facilities to reduce their carbon intensity through feedstock switching. For instance, Pacific Ethanol reported that in the 3rd quarter of 2012, about 30 percent of its feedstock was sorghum. Furthermore, Pacific Ethanol has partnered with Edeniq to expand production through the installation of Edeniq's Cellunator™ - a technology that has the potential to improve yields at the plant by 2-4 percent. Similarly, Aemetis recently idled its 60 million gallon per year production plant in Keyes, California plant to upgrade the facility so that it can also operate using sorghum as a feedstock for ethanol production. Aemetis has since restarted its facility and announced a multi-year agreement with Chromatin to supply locally grown sorghum.

Edeniq is funded in part by a $3.9 million grant from the CEC's Alternative and Renewable Fuel and Vehicle Technology Program to help existing corn ethanol production facilities upgrade via addition of Edeniq's cellulosic ethanol production technology.

Brazilian sugarcane ethanol

For the purposes of this project, the ICF team sought to limit the import of Brazilian sugarcane ethanol to California at levels of 500 million gallons annually in an effort to minimize dependence on this compliance option. Even though this is a significant increase from the most recent volumes of Brazilian sugarcane ethanol imported to California (at least 90 million gallons in 2012), there are three reasons why our team is confident that Brazilian sugarcane ethanol will continue to play a significant role in compliance: 1) Brazil has sufficient capacity to meet demand for ethanol, 2) the fuel is priced competitively with corn ethanol, and 3) there is potential to lower the carbon intensity of sugarcane ethanol further. These issues are discussed in more detail here.

Brazilian sugarcane ethanol: Export capacity

Firstly, Brazil has sufficient capacity to export significantly higher volumes of ethanol. In 2012, Brazil exported approximately 800 million gallons of sugarcane ethanol, with about two thirds of that (530 million gallons) coming to the United States. The majority of Brazil's ethanol is exported from the Port of Santos and is either delivered to California via Los Angeles or San Francisco. It is also feasible for the ethanol to be imported via Houston and shipped to California via rail; however, it is unclear how common this practice is. The most recent data from EIA for 2013 indicate that fuel ethanol imports to the US are considerably higher than in the same period in 2012. Through the end of April 2013, the US has imported approximately 100 million gallons of fuel ethanol, up from just 23 million gallons over the same period last year. Furthermore, the likelihood of lower sugar prices and an abundant sugarcane crop for 2013 have led most analysts to project Brazilian ethanol production upwards of 7 billion gallons, up from 5.6 billion gallons over the last couple of years.[4]

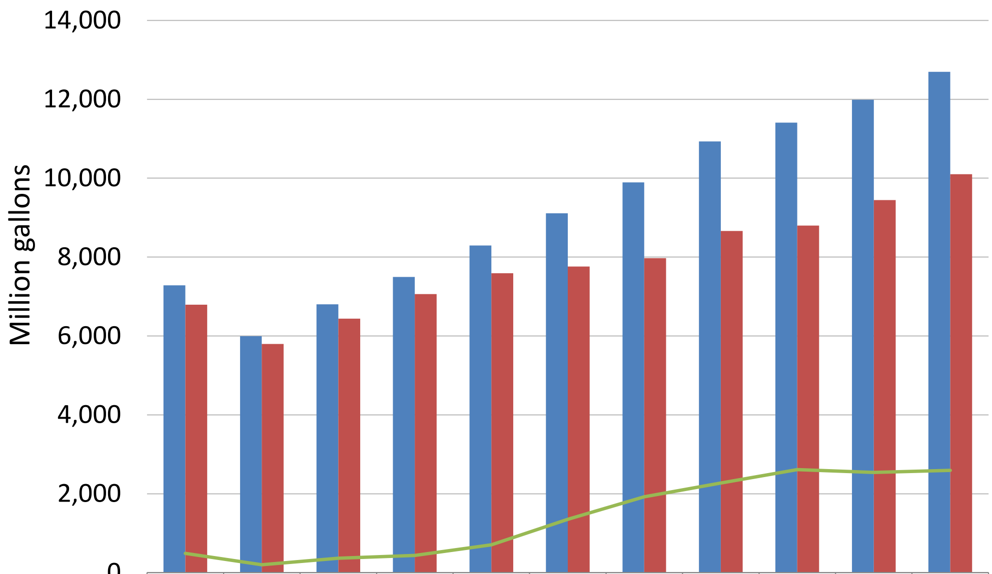
The figure below highlights the Organisation for Economic Co-operation and Development's (OEC) forecast of Brazil's production, consumption, and net export of ethanol out to 2020.[5] Note

[4] Irwin, S and Good, D. Brazilian Ethanol Imports – Implications for US Ethanol and Corn Demand. Farmdoc Daily, University of Illinois, Dept of Agricultural and Consumer Economics, May 2013. Available online at. http://farmdocdaily.illinois.edu/2013/05/brazilian-ethanol-implications.html

[5] OECD-FAO. "Agricultural Outlook: 2012-2021". OECD-FAO, 2012.

that even though production in 2012 was down from the forecasted 6.8 billion gallons, exports were more than double the forecasted 365 million gallons.

Exhibit 30. OECD Forecast of Brazil's production, consumption and net export of ethanol



	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Production	7,284	5,997	6,805	7,495	8,294	9,111	9,896	10,932	11,408	11,987	12,695
Consumption	6,795	5,796	6,440	7,061	7,590	7,761	7,972	8,661	8,797	9,444	10,103
Net export	489	201	365	435	704	1,350	1,924	2,271	2,611	2,543	2,592

It is important to note that there will be other export markets for Brazilian sugarcane ethanol. For instance, the European Commission (EC) issued the Fuel Quality Directive (FQD), which requires a six percent reduction in the lifecycle carbon intensity of transportation fuels by 2020, similar to California's LCFS. The EC also has issued the Renewable Energy Directive (RED), which requires 10 percent renewable energy consumption in the transportation fuels market by 2020. Brazilian sugarcane ethanol is likely to play a significant role towards compliance with both of these directives. ICF recently prepared a report for the EC regarding the impact analysis of one of the key provisions of the FQD – in that work, the EC indicated that their internal forecast for Brazilian sugarcane ethanol consumption in the European Union was upwards of 1.3 billion gallons by 2020. Currently, Brazilian sugarcane ethanol exports to the EU are extremely small to non-existent in large part because of tariffs and increased transportation costs. The EU has an import tariff equivalent to about 50 cents per gallon[6] – considerably higher than the *ad valorem* tax (2.5 percent) that is imposed in the US, which is about 7 cents per gallon.[7] Secondly, ICF estimates that the transports costs to the US will continue to be cheaper than those same costs to the EU. Despite these barriers, it seems likely that exports of Brazilian sugarcane ethanol to the EU will increase to comply with the FQD, in part because of limited

[6] The tariff is €0.102 per liter and was converted using current exchange rates for illustrative purposes.

[7] The ad valorem tax is applied at 2.5percent of the value of the imported product, so the tax paid will fluctuate as a function of ethanol prices paid FOB Santos. The 7 cents per gallon is an average based on data from 2010-2012.

ethanol production capacity in the EU. This is one of the reasons that the team sought to limit the import of Brazilian sugarcane ethanol to California.

Brazilian sugarcane ethanol: Price Competitiveness

Recent spot price spreads between ethanol from Brazil (Santos FOB, $2.65 per gallon) and in California (San Francisco and Los Angeles, $2.86) indicate attractive pricing, even after accounting for transportation and a federally imposed *ad valorem* tariff (of 2.5 percent of the total value of the shipment). Even at LCFS credit prices of $40-45, Brazilian sugarcane ethanol produced from average processes (with a carbon intensity of about 74 g/MJ) would only command an 8-9 cent per gallon premium. When blended at 10 percent by volume with California Reformulated Blendstock for Oxygenate Blending (CARBOB), the additional cost is less than a penny per gallon.

Brazilian sugarcane ethanol: Low carbon ethanol

The GHG abatement potential of Brazilian sugarcane ethanol is significant. Even with an indirect land use change (ILUC) emissions factor of 46 g/MJ to its carbon intensity, the pathways for Brazilian sugarcane ethanol range from 58-79 g/MJ. This is one of the major drivers for Brazilian sugarcane ethanol imports to California because it is one of the most cost-effective compliance pathways for regulated parties. The carbon intensity of the sugarcane ethanol only stands to improve moving forward: By 2014, sugarcane producers in Sao Paolo, for instance, will be required to switch from manual harvesting to mechanized harvesting – a process that reduces local air pollution (the fields are burned before manual harvesting) and reduces the average carbon intensity from 73 g/MJ to 58 g/MJ.

Brazilian sugarcane ethanol consumption will likely be bolstered by the recent recommendation from CARB staff that a molasses-to-ethanol pathway be approved for LCFS compliance. Pantaleon Sugar Holdings is producing ethanol from molasses and estimated a carbon intensity of about 23 g/MJ, less than half of the lowest carbon intensity attributed to sugarcane ethanol using mechanized harvesting because it uses a byproduct of the sugar production process. The Pantaleon facility is based out of Guatemala. Given the demand for low carbon biofuels, it is possible that ethanol production facilities using Brazilian sugarcane ethanol – either in Brazil or in CBI countries – implement similar production capabilities to lower the carbon intensity of their product offerings.

Cellulosic ethanol

ICF developed projections for cellulosic ethanol in coordination with Environmental Entrepreneurs (E2). E2 considered the state of financing of various cellulosic ethanol facilities,[8] the likelihood that facilities would be completed, and their proximity to California to determine the maximum potential for cellulosic ethanol consumption in California.

[8] Solecki, M; Dougherty, A; and Epstein, B. Advanced Biofuel Market Report 2012: Meeting US Fuel Standards. Available online at: http://www.e2.org/ext/doc/E2AdvancedBiofuelMarketReport2012.pdf

- E2 identified 27 facilities that are in some advanced stage of financing. These facilities – if completed as announced – would have a combined production capacity of between 337 and 512 million gallons annually by 2015.
- ICF and E2 developed assumptions regarding increased penetration of cellulosic ethanol beyond the initial 27 facilities, increasing the potential capacity of cellulosic ethanol to slightly less than 600 million gallons by 2020.
- Most cellulosic ethanol plants are outside of California; therefore, ICF made assumptions about the percent of the production capacity that would be available to California refineries considering proximity to a cost-effective distribution infrastructure (e.g., rail) and other regulatory drivers (e.g., RFS2). For instance, INEOS Bio built the Indian River County BioEnergy Center, near Vero Beach, Florida – since it is unlikely that this fuel will be shipped to California, even with an LCFS-driven price premium, ICF did not take this facility into account.

ICF understands that there is considerable uncertainty regarding the availability of cellulosic ethanol to achieve California's LCFS. Cellulosic biofuel projects have been slower to come on-line than expected, falling well short of the volumetric requirements established by Congress in 2007 for the RFS2. CARB's original 2009 illustrative compliance scenarios were based, in part, on aggressive cellulosic ethanol volumes as well (even though the LCFS is performance based and allows the most lowest-cost technology to be utilized). Thus, the slower-than-expected advances in cellulosic biofuel production have dominated the discussion regarding both LCFS compliance and RFS2 compliance; however, the scenarios that ICF has developed highlight that cellulosic biofuels are part of a more diverse solution to GHG reductions in the transportation fuels sector. In this regard, the ICF team sought to limit the dependence of the compliance scenarios on cellulosic ethanol availability.

Despite the slower-than-expected deployment of cellulosic ethanol, there is evidence that the industry is looking up. For instance, Edeniq's cellulosic ethanol demonstration facility in Visalia, CA recently completed 1,000 hours of continuous operation, ahead of schedule and higher than projected production. Meanwhile, Zeachem's demonstration facility in neighboring Oregon has had continuous operation since mid-2012 and is producing 250,000 gallons annually, with plans to ramp up to 25 million gallons by 2014.

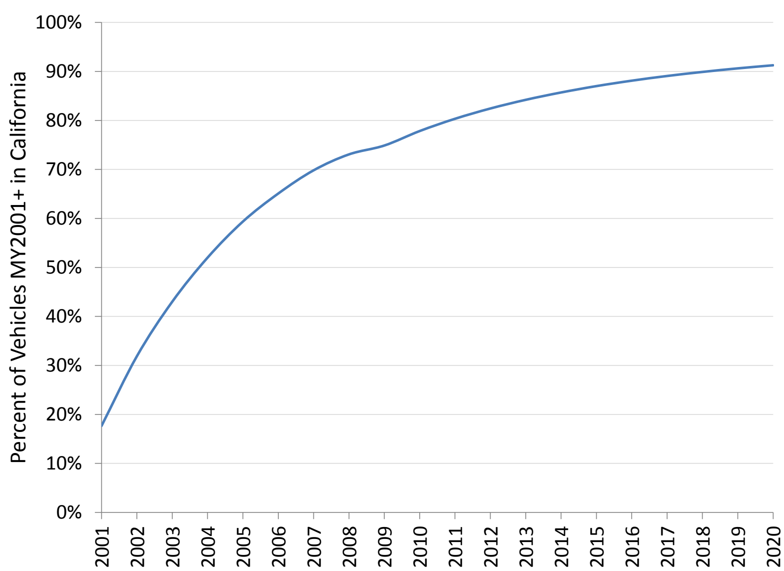
Even in a scenario in which cellulosic ethanol continues to struggle to achieve expected market penetration, innovation is occurring with other waste feedstocks. Most recently, Pantaleon Sugar Holdings applied for a pathway using molasses to produce ethanol with a carbon intensity of 22.75 g/MJ.

Higher blends of ethanol

As noted previously, reformulated gasoline includes 10 percent by volume ethanol. In order to achieve LCFS compliance, ICF considered the potential to move to higher blends of ethanol, including E15 and E85. ICF opted to focus on the introduction of E15 to increase ethanol volumes in California. The US EPA recently approved waivers for E15 consumption in model year 2001 and newer light-duty vehicles. There is considerable uncertainty today regarding the timing of E15 deployment in California. In order for the fuel to be sold in California, CARB would likely initiate a multi-media evaluation and would require modification of the predictive model used for gasoline formulations. Although original equipment manufacturers (OEMs) have strongly expressed hesitation regarding the use of E15 in vehicles, in order for regulated parties (i.e., refiners) to comply with the RFS2, they will likely have to move to higher blends of ethanol such as E15.

ICF used EMFAC2011[9] to estimate the percent of light-duty vehicles (passenger cars and light-duty trucks) that will be model year 2001 (MY2001) or newer by 2020, as shown in the figure below. ICF used this penetration curve to determine the maximum capacity of E15 that could be sold in California. As shown below, by 2018 90 percent of California's light-duty vehicle fleet is anticipated to be MY2001 or newer. An additional 600-650 million gallons of ethanol annually could be blended into gasoline by transitioning to E15.

Exhibit 31. Percent of Light-duty Vehicles MY2001 or Newer in California Fleet



We did not consider the potential for expanded E85 consumption in our scenarios. The potential expansion of the ethanol market via a transition to E15 is similar to the upper limit of an E85 market, assuming that flex-fuel vehicle (FFV) sales were to increase modestly over the next 5 years. Most recently, California drivers have consumed between 10-15 million gallons of E85 in FFVs. There are between 400,000 and 500,000 FFVs on the road in California today. This level of deployment indicates that theoretical consumption would peak around 240 million gallons if FFV drivers were to fuel their vehicles exclusively with E85.

One of the reasons we did not consider E85 more closely is because California drivers do not buy many FFVs. For instance, based on light-duty vehicle sales from 2012 reported by the California New Car Dealers Association (CNCDA), about 115,000-130,000 vehicles sold in California have FFV options. This does not mean that all of these vehicles sold were FFVs; rather, they had FFV models available. This represents about 8-10 percent of the market for

[9] The EMAFC model is issued by CARB and includes the emission factors that represent vehicle fleet, speeds, and environmental conditions associated with a project that are needed to perform project-level air quality modeling. More information is available online at: http://www.arb.ca.gov/msei/modeling.htm

light-duty vehicles and highlights one of the major challenges facing the E85 market: Of the top 10 top selling light-duty vehicles in California for 2012 – Toyota Prius, Honda Civic, Toyota Camry, Honda Accord, Toyota Corolla, Honda CRV, the Ford F-Series, Nissan Altima, Hyundai Sonata, and Toyota Tacoma – only the Ford F-Series offers a FFV model. These 10 models account for nearly 25 percent of the market, and only 7 percent of those sales (or 2 percent of the entire market) has an FFV alternative. In other words, absent changes in vehicle offerings from OEMs such as Toyota, Honda, and Nissan, it is unlikely that California's FFV population will increase significantly over the next 5 years.

4.2. Renewable Gasoline

Renewable gasoline is the term used for biomass-to-liquid processes – such as gasification, pyrolysis, or biochemical processes – that yield a product that can be used as a transportation fuel. The fuel is typically produced in several steps. For instance, fast pyrolysis of biomass yields a bio-oil that needs to be upgraded via hydrotreating; the stabilized oil can then be hydrocracked to produce renewable gasoline. Renewable gasoline is chemically similar to conventional gasoline, and in principle, can be distributed and combusted in the existing infrastructure and vehicles. For the purposes of this analysis, ICF assumed that 50 percent of the forecasted renewable gasoline produced in the United States would be available to California.

Companies such as Dynamic Fuels, KiOR, Sundrop, and UOP all are building commercial plants to manufacture these types of biomass-to-liquid fuels. Similarly, there are other firms, including Ensyn, Sapphire, and Solazyme that are seeking to produce a stable renewable oil from biomass or sugars that can be processed into renewable gasoline, renewable diesel, or renewable jet fuel. The long-term viability of renewable gasoline will be largely dependent on the ability of biofuel producers to reduce the costs of producing a stable oil for processing, which is currently the most expensive production process (see the table below).

Exhibit 32. Renewable Gasoline Production Costs via Pyrolysis (Haq, 2012)

Production Element	Production Costs ($/gallon)		
	2009 State of Technology	2012 Projection	2017 Projection
Feedstocks	$1.33	$0.99	$0.75
Feed drying, sizing, fast pyrolysis	$0.54	$0.52	$0.34
Upgrading to stable oil	$4.69	$2.01	$0.47
Fuel finishing	$0.30	$0.29	$0.11
Balance of plant	$0.82	$0.74	$0.65
Total	**$7.68**	**$4.55**	**$2.32**

Source: Haq, Z; Advanced Biofuels Cost of Production, October 2012. Available online at: http://www1.eere.energy.gov/biomass/pdfs/aviation_biofuels_haq.pdf

Although there have been significant advances in the production cost, the 2017 projections reported in the table above will require significant advances in technology and a stable supply of affordable feedstock. The $0.75 per gallon feedstock projection is equivalent to about $50 per dry ton of biomass; this is a commonly sourced estimate for the cost of biomass for biofuel production. However, ICF urges caution regarding cost projections for waste-based or byproducts because there is so much uncertainty in these markets. This uncertainty is attributable to the markets for many of these products being either emerging or nonexistent; therefore, it is unclear how market pricing will evolve. Despite these notes of caution, ICF's assumptions regarding the availability of renewable gasoline to the California market are conservative, and reach a maximum of about 90 million gallons by 2020.

4.3. Biodiesel

The significant potential for biodiesel to play a key role in LCFS compliance is being realized through a variety of industry investments. As a result of the LCFS and the recent extension of the Biodiesel Mixture Excise Tax Credit, 2013 promises to be a banner year for biodiesel consumption in California.

Biodiesel Production

The biodiesel industry has struggled in recent years with a significant portion of domestic capacity idled as a part of challenging economics. The extension of the tax credit for biodiesel blending will improve the industry's performance for 2013; however, the mid- to long-term outlook is unclear. In California, however, biodiesel consumption is poised to expand rapidly in large part due to very low levels of consumption in recent years (in the range of 20-25 million gallons in 2010, for instance).

There are several significant developments that have and will continue to support increased biodiesel consumption in California. Most notably, the low carbon intensity of biodiesel from corn oil reported by CARB in late 2011 has been a significant driver in the LCFS market to date. To a lesser degree, the low carbon intensity of other feedstocks such as recycled or waste oils has also played an important role in the early stages of LCFS compliance. Biodiesel consumption, mandated through RFS2, was 800 million gallons and one billion gallons in 2011 and 2012, respectively. Biodiesel production has exceeded these targets in both years, however, production volumes were about the same in 2011 and 2012.

As shown in the table below, the production of biodiesel from corn oil and recycled feedstocks were the only two to increase between 2011 and 2012. There is increasing evidence to suggest that these numbers are driven in part by California's LCFS, largely because these feedstocks yield biodiesel with a low carbon intensity. Furthermore, these feedstocks are generally cheaper than soy oil; for instance, corn oil has been selling in the range of 32-38 cents per pound for the past 18 months whereas soybean oil has been selling for closer to 50-55 cents per pound.

Exhibit 33. Feedstock Consumption for Biodiesel Production in the United States, 2011-2012

Feedstock	Feedstock Consumption for Biodiesel (million lbs)		
	2011	2012	Change
Canola Oil	847	787	-60
Corn Oil	304	571	267
Soybean Oil	4,153	4,023	-130
Animal Fats [a]	1,289	840	-449
Recycled Feeds [b]	666	900	234
Total	7,259	7,291	32

a. Includes poultry, tallow, white grease, and other.
b. Includes yellow grease and other.
Source: EIA

The nationwide potential for corn oil is significant: with a yield of approximately 5-7 gallons of corn oil per 100 gallons of corn ethanol, the upper limit of nationwide production is about 720 million gallons in 2020 according to the EIA. By the end of 2011, approximately 40 percent of ethanol production facilities in the US had corn oil extraction in place, and this likely increased further in 2012. ICF research indicates that nearly every corn ethanol production facility that can be retrofitted for corn oil extraction will have done so by the end of 2014. In California, for example, Pacific Ethanol announced plans in November 2012 to install a corn oil extraction system at its Stockton, California plant.

The scenarios developed for our study include 175-240 million gallons of corn oil biodiesel in 2020, representing a maximum of one third of domestic production in the same timeframe. With a carbon intensity of 4 g/MJ and LCFS credits trading at $40-45, the implied premium for corn oil biodiesel today is 47-53 cents per gallon. The LCFS market is likely to remain a strong driver for corn oil biodiesel consumption in California. Given that there is currently no parallel premium for corn oil biodiesel at the national or other state level, our team is confident that our assumptions regarding California consumption of corn oil biodiesel are conservative.

The scenarios also include about 50 million gallons of biodiesel produced from waste grease. Similar to corn oil, with a low carbon intensity and significant potential to expand the biodiesel market in California, we see the LCFS as a significant driver for biodiesel producers that can use feedstocks such as waste grease and animal fats.

In addition, the production of biodiesel in California has been boosted by awards from the CEC's Alternative and Renewable Fuel and Vehicle Technology Program. For instance, the program has awarded:

- Buster Biofuels received a $2.6 million grant for a production facility in the San Diego area that will produce about 5 million gallons per year.

- Eslinger Biodiesel Inc. received a $6 million grant to help build a biodiesel production facility in Fresno with an initial capacity of 5 million gallons per year, with potential expansion up to 45 million gallons per year.
- Springboard Biodiesel LLC received about $760,000 towards the construction of a pilot production facility in Chico with an annual production capacity of about 365,000 gallons.

Biodiesel Infrastructure and Vehicle Compatibility

With regard to infrastructure, pipeline operators and storage terminal operators are expanding storage capacity and biodiesel handling/blending capabilities significantly. As recently as 2010, the CEC reported that biodiesel terminal storage was severely limited.

Kinder Morgan made significant investments to expand biodiesel storage and delivery capacity at its Fresno and Colton terminals, with a reported throughput of 19 to 20 million gallons per year at each facility. As of late last year (2012), Kinder Morgan informed wholesalers that it will only sell B5 (a blend of 5 percent biodiesel with conventional diesel) at its Fresno and Colton facilities. Chevron made a similar announcement regarding the exclusive delivery of B5 at its facility in Montebello. Interviews with industry representatives indicate that at least four (4) refiners within California have proprietary terminals at which they are or have the capacity to blend biodiesel. ICF research indicates that there are at least 230,000 barrels of biodiesel storage capacity in California today. If we assume conservatively that these storage tanks have about 75 turns per year (i.e., the number of times each tank is emptied and filled) and that biodiesel represents about 15 percent of throughput at these facilities, then we estimate a biodiesel blending capacity of around 110 million gallons annually.

Based on ICF analysis and interviews with industry stakeholders, we anticipate storage capacity and blending capabilities in California to continue increasing over the next several years. The low-level biodiesel blend market (B5) will saturate around 200 million gallons per year. There is still significant potential to increase biodiesel blending beyond B5; however, higher blends of biodiesel will require more investment in retail infrastructure and consideration of engine manufacturer warranties, as discussed below.

- **Refueling infrastructure**. Most underground storage tanks (USTs) that are manufactured to store petroleum diesel blends can store B100 (i.e., pure biodiesel);[10] however, it's important to confirm that tank materials such as aluminum, steel, fluorinated polypropylene, and fiberglass make up the tank structure to ensure that degradation does not occur when using biodiesel. These materials must also be used in biodiesel fueling equipment to ensure that piping, spill and release detection equipment, dispensers, and dispenser nozzles are compatible with biodiesel blends.[11] Equipment materials that may lead to oxidation of biodiesel include brass, bronze, lead, zinc, tin, and copper. The U.S. EPA published final guidance on the subject in Volume 76, No. 28 of the Federal Register on July 5, 2011 to assist owners and operators of USTs in complying with the federal UST compatibility requirements promulgated under the authority of Subtitle I of the Solid Waste Disposal Act

[10] Petroleum Equipment Institute, UST Component Compatibility Library, Available online at: http://www.pei.org/PublicationsResources/ComplianceFunding/USTComponentCompatibilityLibrary/tabid/882/Default.aspx

[11] Oregon Department of Environmental Quality, "Biodiesel and Underground Storage Tank Systems", Available online at: http://www.deq.state.or.us/lq/pubs/factsheets/tanks/ust/BiodieselUSTSystems.pdf

(SWDA).[12] This guidance applies to biodiesel blends over 20 percent biodiesel that are stored in USTs. Currently, all newly manufactured USTs are compatible with blends of up to 100 percent biodiesel; however, EPA requires all UST manufacturers to provide a statement of compatibility for their products with biodiesel blends.

- **Engine warranties.** All diesel engine manufacturers selling into the US market provide warranties supporting blends of B20 or higher. The National Biodiesel Board has developed a summary table outlining OEM statements as they pertain to biodiesel blends – with the majority of engine manufacturers indicating that B20 can be used when it meets certain specifications such as ASTM D 6751 or fuel that is sourced from a BQ-9000 accredited producers.[13] Some notable exceptions of vehicle manufacturers that do not warranty above B5 include Kenworth and Peterbilt. Both are divisions of PACCAR Inc., which are still studying approvals for their trucks. It is also noteworthy that the engine manufactures supplying PACCAR have already approved B20.

The CEC has invested a modest amount of funding from the Alternative and Renewable Fuel and Vehicle Technology Program in biodiesel infrastructure, including:

- Pearson Fuels, in partnership with SoCo Group Inc. and InterState Oil Company received $1.8 million in grant funding to build two new biodiesel terminals with in-line blending capabilities.
- Whole Energy Pacific received about $125,000 to design, build, and install a biodiesel blending facility in Richmond, CA.

4.4. Renewable Diesel

Renewable diesel is similar to renewable gasoline in that it is produced via biomass-to-liquid processing. Renewable diesel, however, is currently being produced, primarily via hydrogenation of bio-oils, in commercial quantities and being consumed in California. In terms of chemical and physical properties, renewable diesel meets all the requirements of ASTM D975; in fact, Neste Oil's NExBTL product meets the fuel quality specifications of CARB diesel, meaning no modifications are needed to existing storage and transport infrastructure.

Neste Oil has been the most aggressive producer shipping renewable diesel to California. In 2010, Neste invested billions of dollars to build renewable diesel production plants in Singapore and Rotterdam (the Netherlands), in addition to facilities in Finland. All four of these facilities are operational; the Singapore plant is well situated to deliver renewable diesel fuel to California. Neste has estimated that they will deliver about 100 million gallons of renewable diesel to consumers in California in 2013. Neste's NExBTL process is capable of using multiple feedstocks: Although the Singapore facility uses palm oil, which does not have a pathway under California's LCFS, the facility also uses tallow from Australia. The tallow based renewable diesel has a carbon intensity of around 33 g/MJ.

The renewable diesel industry will be expanding significantly in the near-term with the completion of Diamond Green's production facility in Norco, Louisiana. Diamond Green – a joint

[12] Federal Register, "Volume 76, No. 2", July 5, 2011, http://www.gpo.gov/fdsys/pkg/FR-2011-07-05/pdf/2011-16738.pdf

[13] Available online at: http://www.biodiesel.org/using-biodiesel/oem-information/oem-statement-summary-chart

venture between Valero and Darling International Inc – has a reported production capacity of 137 million gallons per year. Although the project is behind schedule, the most recent reports indicate that the facility will be online by the second quarter of 2013. Diamond Green has indicated to CARB that it plans to use four feedstocks for renewable diesel production at its facility: soy oil, corn oil, used cooking oil, and animal fat.[14]

4.5. Natural Gas

To develop natural gas projections, ICF consulted with the natural gas transportation fuel industry, analyzed trends within the natural gas market place and used the National Petroleum Councils Future Transportation Fuels Study.[15]

Recent advances in technology used to extract natural gas have drastically changed the landscape for natural gas in many applications. In the transportation sector, ICF considered the potential for increased natural gas consumption given the dramatic increases in supply, an expanding retail fueling infrastructure, and more vehicle offerings. Furthermore, the long-term potential for significant GHG reductions from natural gas in the transportation sector is tied to the deployment of biogas.

Increased Supply of Natural Gas

The increased discovery and production of shale gas reserves in the United States, including the Monterey Shale in the San Joaquin Basin, has decreased the cost of natural gas for all applications including electricity generation and transportation. Natural gas can be used as a transportation fuel as both compressed (CNG) and liquefied (LNG). CNG is favored in medium and light heavy-duty applications where there is a lower VMT per day and refueling can take place each night. This includes many local and regional commercial fleets and transit bus applications. LNG is preferred for heavy-duty applications with higher VMT such as long-haul trucking due to the increased energy density over CNG that requires less refueling.

Natural gas, due to its much lower fuel price, has the potential to contribute significantly to the future transportation fuel mix in California. This is especially true in Southern California where natural gas is required in certain market segments that include refuse applications. The greatest potential market for natural gas is in the medium and heavy duty commercial fleet and transit agency market segments, with significant annual VMT and a heavy emphasis on lifecycle cost. The higher annual VMT takes advantage of the lower fuel price compared to gasoline (medium-duty) and diesel (heavy-duty) and decreases the time needed for payback of the increased vehicle costs.

Expanding Retail Infrastructure

There are still limitations on natural gas as a transportation fuel including infrastructure and vehicle costs. Both CNG and LNG require additional and costly infrastructure to expand access.

[14] More information is available online at: http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/dgd-sum-120112.pdf

[15] NPC Future Transportation Fuels Study: Advancing Technology for America's Transportation Future. Available online at: http://www.npc.org/FTF-80112.html

Natural gas' future in the transportation fuel market is evidenced by significant industry investments in refueling infrastructure. Clean Energy Fuels has teamed up with Pilot Flying J truck stops to create a nationwide network of natural gas refueling stations called America's Natural Gas Highway. As of February, the first 70 of the planned 150+ stations have been constructed. In addition, Clean Energy built 127 stations in 2012 for transit, refuse and airport applications. Shell has an agreement to build refueling stations at as many as 100 TravelCenters of America and Petro Stopping Centers and ENN, a privately held Chinese company, hopes to build 500 filling stations.[16]

To date, the CEC has awarded over $16 million towards natural gas fueling infrastructure through the Alternative and Renewable Fuel and Vehicle Technology Program.

Increased Vehicle Availability

On the vehicle side, UPS is seeking to increase their use of LNG vehicles over seven fold – from 112 to 800 – by the end of 2014, and companies such as Walmart are testing the use of natural gas[17] in their California fleet. Cummins-Westport is the main manufacturer of heavy-duty natural gas engines to date; they recently announced the availability of the Cummins ISX12 G engine, which will be in full production by August 2013. Cummins Westport also announced that it is developing the ISB6.7, a mid-range 6.7 L engine with plans for full production by 2015.

Apart from development in the heavy-duty engine market, there are an increasing number of natural gas vehicle offerings in lower weight categories. For instance, GM introduced the bi-fuel Chevrolet Silverado and GMC Sierra 2500 HD; these packages start at around $11,000. Meanwhile, Chrysler is offering the Ram 2500 CNG to retail customers. Similarly, Westport Innovations now has conversion kits for Ford's F series of medium-duty trucks – one of the top 10 selling vehicles in California during 2012 – at a retail price of $9,500. Wesport's WiNG technology is a bi-fuel system that has been demonstrated and deployed with success in the F-250 and F-350 models; and Westport recently announced that they are expanding the offering to the F-450 and F-550 trucks.

At price increments of $9,500-$11,000 and using current fuel pricing forecasts with natural gas about half to two thirds the cost of diesel, most consumers will see a two-to-three year payback period, which will push sales of natural gas vehicles higher.

Cummins Westport's advances in heavy-duty engines and increased OEM and conversion kit offerings in medium-duty trucks portend significantly higher sales of CNG and LNG in the near-term future. The volumes of natural gas in each of the compliance scenarios only require modest increases in new vehicles sales. For instance, if natural gas vehicles were able to capture 10-15 percent of new vehicles sales by 2020 in targeted vehicle segments, then this would displace upwards of 600 million gge. This would be in addition to California's existing natural gas consumption in the transportation sector of around 120 million gge.

[16] http://www.nytimes.com/2013/04/23/business/energy-environment/natural-gas-use-in-long-haul-trucks-expected-to-rise.html?pagewanted=all&_r=1&

[17] http://www.walmartstores.com/sites/responsibility-report/2012/fleetImprovements.aspx

To date, the CEC has awarded more than $28 million to natural gas vehicles within California through the Alternative and Renewable Fuel and Vehicle Technology Program.[18]

Biogas: Transition to a Lower Carbon Fuel

In the context of the LCFS, another driver for increased use of natural gas is biogas.[19] Biogas converted to CNG and LNG has some of the lower carbon intensity values evaluated by CARB. There is growing interest from regulated parties and natural gas fueling companies to invest in biogas projects since they have the potential to be a significant source of LCFS credits. Based on conversations with industry sources and operational projects sending biogas to California, an estimated 10 percent of natural gas used as a transportation fuel will be coming from biogas due to the LCFS.

4.6. Advanced Vehicle Technologies: PEVs and FCVs

Electricity and hydrogen used PEVs and FCVs, respectively, promise to play significant roles in LCFS compliance, particularly in the later years of program implementation. By 2020, estimated electricity and hydrogen consumption associated with PEV and FCV deployment in CARB's most likely compliance scenario account for nearly five percent of all credits generated.

Vehicle Sales

CARB's most likely compliance scenario yields about 500,000 ZEVs by 2020. Scenario 1 includes 1.13 million ZEVs and the LCFS Enhanced Scenario includes 1.31 million ZEVs by 2020. The projections for Scenario 1 are consistent with the types of sales that would be needed to achieve the long-term goal of the Governor's ZEV Action Plan,[20] which would yield 1.5 million ZEVs on the road by 2025.

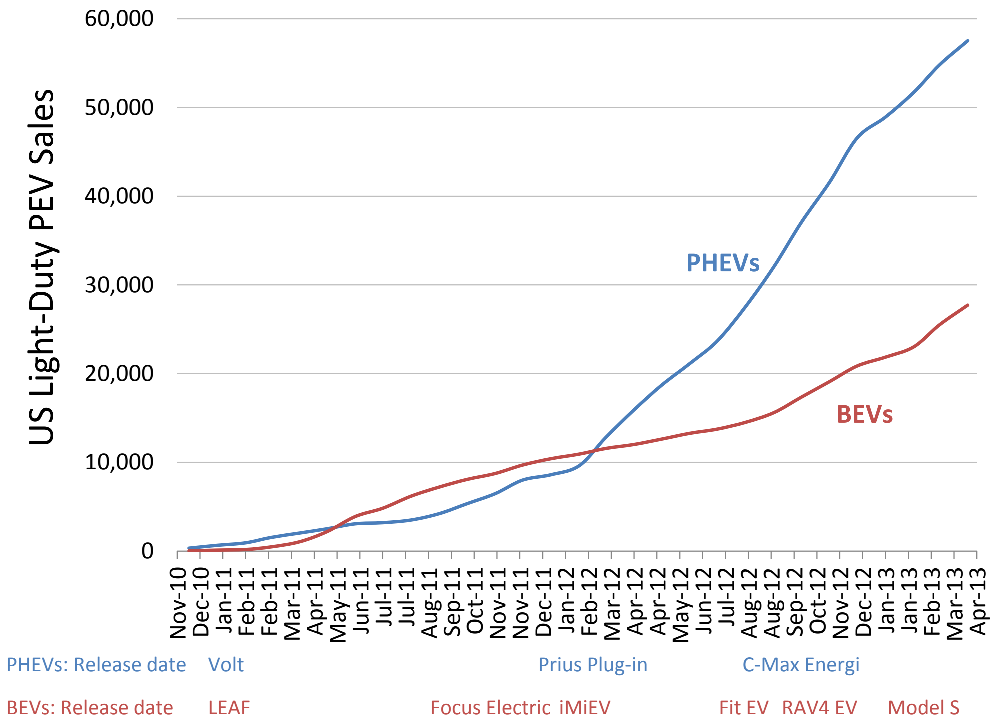
PEV sales in the US have been below some analysts' expectations; however, the initial data indicate that the vehicles are selling at a better rate than the original deployment of hybrid electric vehicles (HEVs) in the early 2000s. Moreover, sales have been bolstered by far more PEV offerings compared to the initial launch of HEVs (see figure below for cumulative PEV sales in the US; the model of vehicles at the bottom of the graph indicate when those became commercially available): Each major OEM is now selling either a PHEV or BEV, and they are competing with upstarts such as Tesla Motors.

[18] http://www.energy.ca.gov/2012publications/CEC-600-2012-008/CEC-600-2012-008-CMF.pdf

[19] Biogas is the gaseous product of anaerobic digestion (decomposition without oxygen) of organic matter.

[20] 2013 ZEV Action Plan: A roadmap toward 1.5 million zero-emission vehicles on California roadways by 2025, Office of Planning and Research. First Draft available online at: http://opr.ca.gov/docs/Governor's_Office_ZEV_Action_Plan_(02-13).pdf

Exhibit 34. Cumulative PEV Sales in the United States through April 2013



Most analysts estimate that about 35-40 percent of PEV sales nationwide are in California. Consumers are drawn to incentives such as rebates of $1,500 for PHEVs and $2,500 for BEVs from the Clean Vehicle Rebate Project (CVRP) and the Green or White Clean Air Vehicle Stickers that provide single occupant vehicles use of high occupancy vehicle (HOV) lanes. The CVRP has been so successful that CARB and CEC recently agreed to add $6 million and $4.5 million respectively to the rebate program's funds to extend the availability of funds until next year's funds are available. Even with the success of the CVRP, conversation with staff at the California Center for Sustainable Energy (CCSE), which administers the CVRP, indicate that there are still a significant number of PEV buyers do not take advantage of the rebate program. CCSE worked with OEMs to determine that in some cases, only 75 percent of owners of select PEVs apply for the rebate.

The PEV deployment scenarios assume that OEMs will continue to have more vehicle offerings at more attractive pricing out to 2020. The more aggressive scenarios include higher penetrations of PHEVs, with more modest increases in BEVs and FCVs. This reflects the automotive industry's focus on PHEV technology. For instance, in a recent survey of automotive industry executives, KPMG reports that 29 percent of OEMs and 23 percent of suppliers are making the biggest investments in plug-in hybrid technology over the next five years, second only to investments in internal combustion engine (ICE) downsizing (see table below).[21]

[21] KPMG's Global Automotive Executive Survey 2013: Managing a multiidimensional business model. Available online at: http://www.kpmg.com/SK/en/IssuesAndInsights/ArticlesPublications/Documents/Global-automotive-survey-2013.pdf.

Exhibit 35. Percentage of OEMs and Suppliers Making Investments in Powertrain Technologies in the Next 5 Years

Powertrain technologies	OEMs	Suppliers
ICE downsizing	31%	24%
Plug-in hybrid	29%	23%
Hybrid fuel systems	18%	11%
Battery (range extender)	10%	18%
Pure battery	6%	13%
Fuel cell	6%	11%

Source: KPMG Global Auto Executive Survey 2013

Some OEMs have already taken aggressive measures to increase PEV sales. For instance, Nissan LEAF cut the price of the LEAF by $6,400 in 2013, leading to a significant resurgence in sales approaching 5,500 vehicles in the first four (4) months of 2013, or 2.5 times more LEAFs sold in the same period in 2012. Information from Tesla's recent first quarter filings also indicate the competitive nature of the PEV industry. Tesla's first quarter earnings were bolstered considerably by the sale of ZEV credits to other OEMs. Tesla's financial filings indicate sales of $68 million of ZEV credits;[22] each of Tesla's vehicles generated five ZEV credits because their vehicles have a range greater than 200 miles. With estimated sales of 4,900 vehicles, this values the credits at about $14,000 per vehicle. Going forward, there will be a strong financial incentive for other OEMs to develop ZEVs rather than paying out such large sums to competitors like Tesla.

Vehicle sales will likely also be bolstered by decreasing battery prices. Apart from technological improvements and economics of scale, the global capacity of lithium-ion battery manufacturing is drastically over-supplied. For 2013, global production capacity is estimated to be nearly 4,000 MW; however, the demand for batteries is an order of magnitude less – around 400 MW. This over-supply will likely lead to industry consolidation in the next several years and may yield lower battery prices.

CARB and CEC continue to report via surveys of major OEMs that they are planning on rolling out tens of thousands of hydrogen fuel cell vehicles in California over the next 2-4 years. As recently as 2012, OEMs indicated that they plan on achieving sales upwards of 55,000 vehicles by 2017 in California. These numbers are bolstered by action: Hyundai recently announced the limited assembly-line production of its ix35 FCV, and although the vehicle will likely be sold in Europe for the first several years of production, it portends positive developments in the fuel cell vehicle industry.

Fueling Infrastructure for ZEVs

There has been a major push to deploy sufficient infrastructure for PEV and FCV adoption:

[22] Tesla Motors Inc – First Quarter 2013 Shareholder Letter. Available online at: http://tinyurl.com/Tesla1Q

- Level 2 Electric Vehicle Supply Equipment (EVSE) and DC fast charging EVSE are being deployed rapidly around the State of California using grant funding provided by the Department of Energy (DOE) and CEC. Many EVSE were deployed as part of ECOtality's EV Project and Coulomb Technologies' ChargePoint America.
- Furthermore, another $100 million will be spent by NRG as part of a settlement with the California Public Utilities Commission (CPUC) – these funds are dedicated to installing at least 200 so-called Freedom Stations (i.e., DC fast charging EVSE) and 10,000 Make-Readies (i.e., the pre-wiring and conduit required for Level 2 EVSE).
- The CEC is coordinating the deployment of hydrogen fueling stations with funding from the Alternative and Renewable Fuel and Vehicle Technology Program. Current estimates indicate that about 20 publicly available stations will be online by the end of 2013, up from eight today.

4.7. LCFS Enhancements

Electricity Consumed in Non-Road Applications

CARB is actively considering proposed changes to LCFS for electricity used in fixed guideway transportation applications and for forklifts. CARB staff are using a methodology similar to the one developed by ICF staff (previously with TIAX LLC) for CalETC as part of another project.[23]

- For electricity used in fixed guideway applications, the National Transit Database was used to calculate energy consumption per mile for transit agencies in California. These data were coupled with ridership data from Los Angeles Metropolitan Transportation Authority (Metro) and Bay Area Rapid Transit (BART). The research team accounted for planned and implemented rail expansions by holding the ratio of passenger to track miles constant for each transit agency.
- For electricity used in forklifts, the research team developed population estimates based on US factory shipments of electric rider (Class 1 and 2) and motorized hand (Class 3) forklifts from 2000-2010. These shipments were pro-rated (conservatively) based on population statistics to develop California-specific estimates. The potential LCFS credits that could be generated were based on an EER of 3.0, assuming that electricity is replacing diesel, an operational frequency of 3,150 hours per year, and an average daily load of 4.36 kW for Class 1 and Class 2 and 1.25 kW for Class 3.

CARB is actively developing the methodology to present to the Board regarding electricity used in fixed guideway applications and forklifts. These areas have significant potential to increase the number of LCFS credits available and improve the outlook for LCFS compliance.

Innovative Crude Recovery Methods

Pursuant to the November Final Regulatory Order for the LCFS, [24]

[23] California LCFS Electric Pathway – On-Road and Off-Road. TIAX LLC, November 2012. Available online at: http://www.caletc.com/wp-content/uploads/2012/12/TIAX_CalETC_LCFS_Electricity_Potential_FINAL.pdf

[24] http://www.arb.ca.gov/fuels/lcfs/CleanFinalRegOrder112612.pdf

> A regulated party may receive credit for fuel or blendstock derived from petroleum feedstock which has been produced using innovative methods. For the purpose of this section, an innovative method means crude production using carbon capture and sequestration or solar steam generation that was implemented by the crude producer during or after the year 2010 and results in a reduction in carbon intensity for crude oil recovery (well to refinery entrance gate) of 1.00 gCO2E/MJ or greater.

Crude oil recovery in California utilizes a significant amount of steam production through its steam flooding and cycling steam injection operations. The California Department of Conservation Oil and Gas production data from January 2011 to June 2012 show 1,300 thousand barrels per day of steam is utilized for crude production. According to the 2009 Annual Report of the State Oil and Gas Supervisor,[25] Forty two percent of steam produced for oil recovery in California comes from cogeneration and the balance from simple once-through steam generator (OTSG). The steam from OTSG is the potential market for renewable steam generation and carbon capture and storage (CCS). ICF estimated the potential credits generated through innovative crude oil recovery based on work that ICF staff (previously working for TIAX LLC) conducted for NRDC.[26] The research included the following assumptions:

- Renewable steam generation technologies such as BrightSource and GlassPoint could offset GHG emissions from combustion and upstream sources while CCS could only sequester those emissions from combustion.
- Based on the Oil Production Greenhouse gas Emissions Estimator (OPGEE) developed by Stanford University for CARB, OTSG requires 401,537 Btu of natural gas/bbl of steam and 1.9×10^8 MMBtu per year of natural gas. From the CA-GREET model, an estimated 66,677 gCO2e/MMBtu are a result of upstream production and transport of natural gas and combustion while 58,350 gCO2e/MMBtu are a result of combustion alone.
- In their analysis, TIAX did not assume an increase in steam production between 2012 and 2020.
- Furthermore, TIAX assumed a maximum total market share of 10 percent of OTSG steam production in 2020 in California is converted to renewable steam generation and CCS and is split equally between them. Because the standard is performance-based, crude production from other regions could also incorporate similar technologies. This potential was not analysed in this study.

Other GHG reduction options along the supply chain for conventional fuels, including reduced venting, flaring, and leakage were not considered. Moreover, improvements to petroleum refinery energy efficiency, the use of combined heat and power, and incorporation of renewable feedstocks or energy inputs at refineries were not included in this analysis. These types of GHG reduction measures are not currently eligible to receive a carbon intensity reduction under the LCFS.

[25] 2009 Annual Report of the State Oil & Gas Supervisor, California Department of Conservation, 2010. Available online at: ftp://ftp.consrv.ca.gov/pub/oil/annual_reports/2009/PR06_Annual_2009.pdf

[26] California Low Carbon Fuel Standard (LCFS): Potential Emission Reductions from Petroleum, TIAX LLC for National Resources Defense Council, February 2013.

5. Next Steps

The first phase of this project has focused on developing LCFS compliance scenarios, harnessing a combination of existing market data with realistic projections of the availability of low carbon fuels out to 2020. These scenarios demonstrate how the LCFS requirements can be achieved through modest changes in the diversity of transportation fuels supplied to California.

5.1. Overview of Macroeconomic Modeling

The second phase of this project focuses on the macroeconomic impacts of the compliance scenarios presented here. ICF is using the REMI model to perform the economic modeling. The REMI model is well suited to assess the dynamic impacts of assessing regulations with impacts into the future, such as California's LCFS. With impacts out to 2020, it is important to have a dynamic model that allows for behavior such as technological change and adaptation. The modeling is performed by determining the changes in economic parameters relative to a reference scenario (or a business-as-usual scenario). Each scenario has associated expenditures in areas such as industry investments required to deploy alternative fuels and consumer expenditures associated with fuel consumption or vehicle purchases. The types of parameters that the macroeconomic impact analysis will consider in detail include the following:

- Changes in gross state/regional product
- Changes in employment and income
- Changes in total economic production
- Inter-industry and aggregate impacts

5.2. Other economic and environmental impacts

Although the second phase of the project focuses on macroeconomic impacts, the ICF team is also assessing the air quality and GHG benefits of the compliance scenarios. Our assessment includes the emission reductions and the corresponding monetization of those benefits. More specifically, our team is investigating the following impacts:

- **Air quality pollutants**: Pollutants are generally considered negative externalities and researchers have attempted to capture the value of avoided emissions in the form of health and environmental benefits. The EPA has developed cost per ton estimates of the health benefits achieved by reducing criteria air pollutant emissions. The health benefits of reducing transportation-related emissions will depend on a large number of local factors, including the overall levels of pollution in the area and the presence of individuals sensitive to air pollution, among others. Further, the unit risk factors, i.e. the estimated health damage per unit of emissions, for several of the emissions are still a matter of research as state and federal agencies differ on their values.
- **GHG emissions**: Recently, estimates have been developed to monetize the benefits of reducing GHG emissions via a parameter termed the social cost of carbon (SCC). The SCC is an economic parameter employed to estimate the economic cost of an addition ton of CO_2-equivalent emissions. More precisely, this term is the "change in the discounted value

of the utility of consumption denominated in terms of current consumption per unit of additional emissions".[27] Most recently, the US government concluded a year-long process to develop a range of values for SCC and these values are to be used in benefit-cost analyses to assess potential federal regulations. In 2007 dollars, the recommended central value is \$21/ton of CO_2 emissions; the final report also recommends conducting sensitivity analyses conducted at \$5, \$35, and \$65.[28]

- **Reduced petroleum dependence**: Paul Leiby at the Oak Ridge National Laboratory (ORNL) estimated the energy security benefits of reduced US oil imports.[29] The research focuses on two components of energy security benefits: monopsony and macroeconomic disruption or adjustment costs. The benefit of displacing imported oil is reported with a mid-point of nearly \$14 per barrel of oil (in 2004 dollars). For the sake of comparison, based on information available from the EIA, about 50% of the oil refined to produce gasoline and diesel is imported. For illustrative purposes, this yields a monetized benefit of reduced U.S. oil imports of about \$0.81 per gallon of diesel or gasoline after adjusting for inflation, with a low/high scenario of \$0.40 and \$1.39 per gallon.

[27] *Estimates of the social Cost of Carbon: Background and Results from the RICE-2011 Model*, Discussion Paper No. 1826, October 2011.

[28] Greenstone et al. *Estimating the Social Cost of Carbon for Use in U.S. Federal Rulemakings: A Summary and Interpretation*, Working Paper No. 16913, December 2011

[29] Leiby, P. Estimating the Energy Security Benefits of Reduced U.S. Oil Imports, Oak Ridge National Laboratory, ORNL/TM-2007/028, 2007. Available online at: http://www.epa.gov/otaq/renewablefuels/ornl-tm-2007-028.pdf