Analyzing Future Low Carbon Fuel Targets in California

Accelerated Decarbonization in California's Transportation Fuels Sector

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Abbreviations and Acronyms

ACC2	Advanced Clean Cars 2 regulation
ACF	Advanced Cleen Fleet regulation
ATJ	Alcohol to Jet
BEV	Battery Electric Vehicle
CARB	California Air Resources Board
CARBOB	California Reformulated Blendstock for Oxygenate Blending
CEC	California Energy Commission
CCS	Carbon Capture and Storage
CI	Carbon Intensity
DAC	Direct Air Capture
E10	Blend of ethanol (10$\%_{vol}$) with CARBOB (90$\%_{vol}$)
E85	Blend of ethanol (85$\%_{vol}$) with gasoline (15$\%_{vol}$)
EMFAC	Emissions Factor model, developed by CARB
EPA	U.S. Environmental Protection Agency
FCEV	Fuel Cell Electric Vehicle
FCI	Fast Charging Infrastructure
FFV	Flexible fuel vehicle
GHG	Greenhouse Gas
HEFA	Hydroprocessed Esters and Fatty Acids
HRI	Hydrogen Refueling Infrastructure
ICT	Innovative Clean Transit regulation
IRA	Inflation Reduction Act
LCFS	Low Carbon Fuel Standard
LFG	Landfill Gas
LUC	Land Use Change
mdge	Million diesel gallon equivalents
MSW	Municipal Solid Waste
PHEV	Plug-in Hybrid Electric Vehicle
RPS	Renewable Portfolio Standard
RNG	Renewable Natural Gas
RVP	Reid Vapor Pressure
SAF	Sustainable Aviation Fuel
USDA	United States Department of Agriculture
WRRF	Water Resource Recovery Facility
ZEV	Zero Emission Vehicle

Executive Summary

The California Air Resources Board is considering setting more ambitious Low Carbon Fuel Standard targets, thereby achieving more significant greenhouse gas emission reductions in support of California's pursuit of carbon neutrality—defined by the state as achieving net-zero GHG emissions as soon as possible, and no later than 2045, and achieving and maintaining net negative emissions thereafter.

ICF modeled carbon intensity reductions that could be achieved using the structure of the Low Carbon Fuel Standard program. The modeling is driven by the demand for transportation fuel in California, which is a function of many variables including but not limited to economic growth, vehicle miles traveled, vehicle fleet turnover, and the expected compliance with complementary policies that impact transportation fuel demand. ICF pairs the fleet turnover and fuel demand functions with supply-cost curves for low carbon fuels. ICF modeling incorporated expected compliance with several regulations that decrease fossil fuel demand, like the Advanced Clean Truck Rule, the Innovative Clean Transit Rule, Advanced Clean Cars II, and the Advanced Clean Fleets Regulation.

ICF is modeling multiple scenarios for this project and framing each as *Accelerating Decarbonization* in the transportation sector using a diverse array of low carbon fuel strategies that are viable in the timeframe contemplated. Within this framework, ICF is focused on a Central Case. In the *Accelerating Decarbonization, Central Case*, ICF limited our consideration of low carbon fuel strategies that require expanded deployment, reasonable technological advancement, and limited, if any, substantive policy changes.

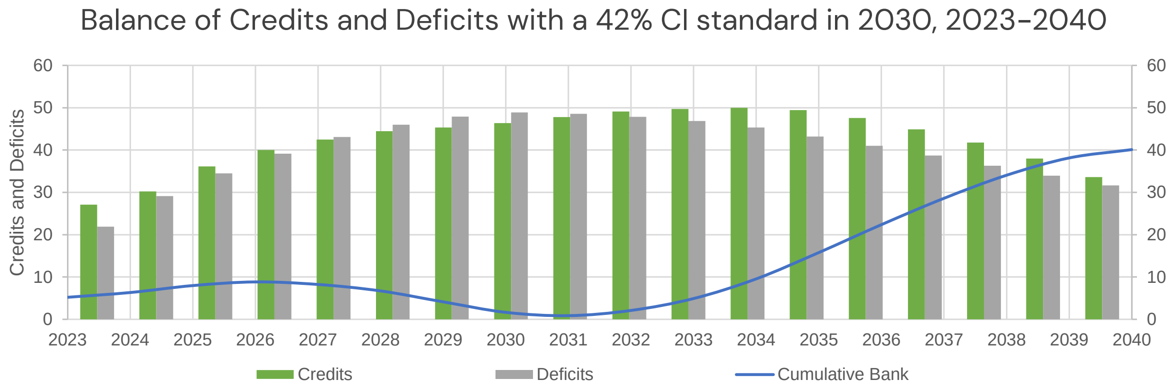
ICF modeling shows that the lifecycle GHG emissions for the transportation sector (including gasoline, diesel, and intrastate jet fuel) can decrease by 42% by 2030 and 77% by 2040 from 2010 values (see table below).

Lifecycle GHG Emissions in California's Transportation Sector

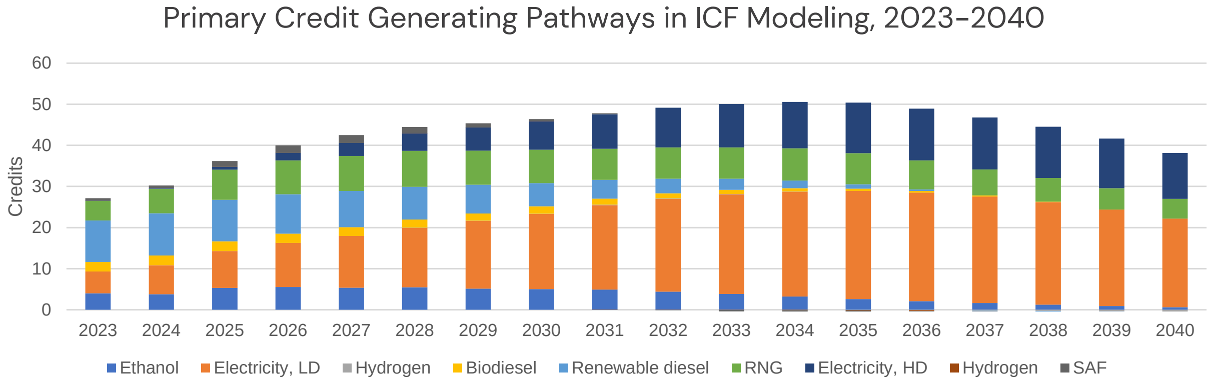
Lifecycle GHG emissions MMT CO2e	2010	2030	2040
Transportation fuels	222	128	51
% Reduction	--	42%	77%

In our modeling, ICF finds that a carbon intensity target of 41-44% for 2030 is achievable in the Central Case based on expected fuel volumes and carbon intensity reductions for a wide array of fuel pathways.

This range excludes many crediting opportunities, including offroad electrification, infrastructure crediting, direct air capture of CO2, carbon capture and storage at biogas or hydrogen facilities, and others. Further, it does not include state goals for reducing vehicle miles traveled, which would lead to significant additional average carbon intensity reductions, assuming low carbon fuel volumes remain the same, otherwise.


Balance of Credits and Deficits with a 42% CI standard in 2030, 2023-2040

Overall, we believe this target represents a reasonable, yet potentially conservative, estimate of CI reduction potential under the LCFS in 2030. We present this as a range, because there is likely some desirable credit bank that the market would seek to maintain, rather than running the bank of credits and deficits to net zero.


Primary Credit Generating Pathways in ICF Modeling, 2023-2040

Based on ICF's analysis of the *Central Case*, we make the following observations:

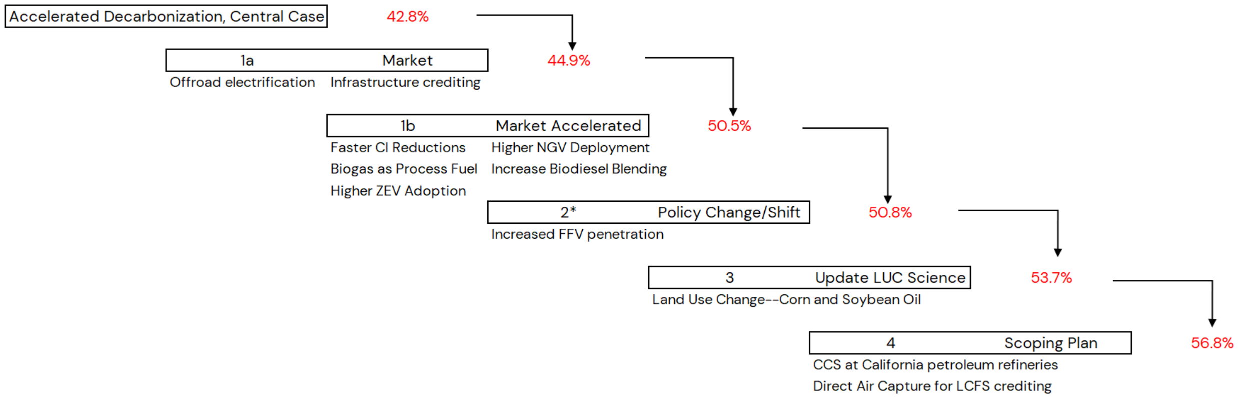
- A trajectory with a 30% carbon intensity reduction requirement by 2030 is borderline untenable—ICF estimates this will yield a bank of more than 100 million excess credits.
- *Deficits are decreasing*. Gasoline and diesel demand are both at or near their peaks; there is only modest room for growth of fossil fuel consumption given California's regulations. This will limit deficit generation considerably in the next decade, especially for gasoline as transportation electrification accelerates.
- *Credit generating activity is poised to increase rapidly*. The diversity of options to achieve the range of carbon intensity reduction targets is significant. We consider higher liquid biofuels blending, lower carbon intensities across the board, electrification of the light-duty and heavy-duty sectors, renewable jet fuel

deployment, expanded role of biogas, and modest hydrogen deployment. These strategies align closely with the incentive structures of the Inflation Reduction Act, and other programs (e.g., the federal Renewable Fuel Standard).

- *A step-down mechanism is needed sooner than later*. The bank of credits will likely be in the range of 30 million credits by the end of 2024 absent intervention—this has the potential to alter the trajectory contemplated in our Central Case. The step-down mechanism is critical for 2024 implementation—another year of banked credits will shift the program trajectory and likely limit low carbon fuel deployment.
- *Diversity of credit-generating options is strength of modeling, not limitation*. Though we have under- and over-estimated credit generation for specific strategies previously, ICF analysis has consistently shown that we are in line with Low Carbon Fuel Standard market performance at the top level of credit-deficit balances. We generally attribute this to our consideration of a diverse set of compliance strategies, rather than narrowing our consideration from the outset.
- *Post-2030 considerations*. The carbon intensity trajectory of the program from 2030 to 2045 will need to be non-linear to prevent another build-up of credits. The full implementation of Advanced Clean Cars II and the Advanced Clean Fleets Regulation will achieve compliance without any other low carbon fuels by 2036 with a 62% carbon intensity standard.

There are several modeling considerations that ICF addressed in an *Accelerated Decarbonization, High Case*. In this case, ICF identified and grouped additional strategies and/or policy changes that would lead to higher deployment of low carbon fuels and/or greater carbon intensity reductions over the course of the analysis. The assumptions in the Accelerated Decarbonization, High Case reflect updated science and analysis, additional cost effective GHG reduction opportunities, and alignment with proposed federal policies. After incorporating these into the modeling, ICF finds that the carbon intensity reduction achieved in 2030 moves from about 43% to about 57% (see figure below).

Summary of CI Reduction Achieved in 2030 in the Accelerated Decarbonization, High Case



Lastly, ICF notes that the cases presented in this report do not include consideration of a step-down mechanism and an acceleration mechanism. A *step-down mechanism* would be designed to reduce significantly the current over-supply of credits. The *acceleration mechanism* is a concept introduced by the California Air Resources Board via workshop to outline an indicator or series of indicators that can be calculated and could be used to determine if the carbon intensity reduction requirements of the program need to be accelerated because of the over-performance in the market. These will be important mechanisms for the Low Carbon Fuel Standard to reduce the over-supply of credits in the near-term, while considering innovative ways to avoid the detrimental build-up of credits in the future.

1 Introduction

About ICF

ICF is a non-partisan, non-political company that delivers a broad and diverse range of independent, unbiased, objective analyses and related consulting services to help its clients meet their missions. ICF has conducted several impactful studies on low carbon fuels programs. Our team has conducted several feasibility and economic impact analyses on California's Low Carbon Fuel Standard (LCFS) since the program's inception, and as part of updates to the program. ICF has also supported the Oregon Department of Environmental Quality in the development and implementation of Oregon's Clean Fuels Program (CFP). We have also conducted similar analysis of low carbon fuel policies for the Puget Sound Clean Air Agency in Washington, the Colorado Energy Office, the Great Plains Institute, and the European Commission.

About the Project

The California Air Resources Board (CARB) is considering setting more ambitious Low Carbon Fuel Standard (LCFS) targets to increase the stringency of the carbon intensity (CI) requirements of the program, thereby achieving more significant greenhouse gas (GHG) emission reductions in support of California's pursuit of carbon neutrality – defined by the state as achieving net-zero GHG emissions as soon as possible, and no later than 2045, and achieving and maintaining net negative emissions thereafter. The current LCFS program includes a linear decrease from the current year (2023) target of 11.25% to 20% by 2030 (with the target being relative to 2010 average carbon intensity levels).

ICF is supporting a coalition of interested parties representing a diverse mix of zero emission vehicle manufacturers, charging companies, low carbon fuel producers and others seeking to understand the potential carbon intensity reduction that could be achieved assuming the likely aggregate deployment of low carbon fuels and supporting technologies. Through consideration of various factors, the project is seeking to quantify what CI target may be achievable in 2030. Furthermore, the project will develop a clearer understanding of the potential interim CI reduction targets that could be achieved between 2024 and 2045.

The objective of this analysis is to demonstrate the levels of CI reduction that could be achieved for the LCFS program under different market conditions and considerations and at what cost. The intent of scenario modeling is to help inform policy development, but it is neither meant to be deterministic with respect to the shape and/or design of any policy, nor is it meant to be prescriptive with regards to compliance. Furthermore, the results are not meant to be predictive forecasts. The scenarios considered represent a bundle of multiple strategies that are designed to reduce the CI of transportation fuels and that industry plans to bring to market given a presumably robust, ongoing LCFS market.

To be clear, the modeling described herein differs from the modeling conducted by others, including modeling by CARB staff using the California Transportation Supply (CATS) model. More specifically, CATS is described as a "transportation fuel supply optimization model" that "minimizes the cost of supplying fuel to meet demand in each year." In other words, given certain modeling constraints, namely a specific CI reduction trajectory, associated policy constraints, and assumed costs and supply constraints, the CATS model optimizes compliance accordingly. The CATS model is designed to answer the question: *What is the least-cost compliance pathway associated with a CI target of X in year Y?* ICF's modeling exercise, however, is seeking to answer a different question: *What is the CI target X that could be achieved in year Y given the supply-demand balance of low carbon transportation fuels into California?*

2 ICF Methodology

ICF modeled the CI reductions that could be achieved using the structure of the LCFS program. The modeling is driven by the demand for transportation fuel in California, which is a function of many variables including but not limited to economic growth, vehicle miles traveled (VMT), vehicle fleet turnover, and the expected compliance with complementary policies that impact transportation fuel demand. ICF's modeling is initiated using documentation associated with the EMissions FACtor model (EMFAC)[1] that is publicly available for download. The EMFAC model is "developed and used by CARB to assess emissions from on-road vehicles including cars, trucks, and buses in California." The EMFAC model enables ICF to characterize top-level transportation fuel demand in California given baseline consideration of the aforementioned key factors, like VMT and fleet turnover. Although EMFAC2021 incorporates expected compliance with several regulations that decrease fossil fuel demand, like the Advanced Clean Truck (ACT) Rule and the Innovative Clean Transit (ICT) Rule, it does not include expected compliance with Advanced Clean Cars II (ACC2) or the Advanced Clean Fleets Regulation, which were adopted by the Board in 2022 and 2023, respectively. ICF modified EMFAC2021 to ensure compliance with ACC2 and ACF. ICF then pairs the fleet turnover and fuel demand functions of EMFAC with supply-cost curves for low carbon fuels, including ethanol, biodiesel, renewable diesel, and renewable natural gas (RNG).

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[1] ICF used the most recent version of EMFAC, EMFAC2021 (v1.0.2) as a starting point for our modeling. The EMFAC model is available for download online.

ICF modeled two scenarios for this project and frames each as *Accelerating Decarbonization* in the transportation sector using a diverse array of low carbon fuel strategies that are viable in the timeframe contemplated. The body of this report presents the Central Case, whereas the Appendix presents our findings related to the High Case.

- *Accelerating Decarbonization, Central Case*: ICF's primary reporting is this case, whereby we limited our consideration of low carbon fuel strategies that require expanded deployment, reasonable technological advancement, and limited, if any, substantive policy changes. The body of this report reviews the key modeling inputs and results associated with the Central Case.
- *Accelerating Decarbonization, High Case*: In this case, ICF considered additional strategies and/or policy changes that would lead to higher deployment of low carbon fuels and/or greater CI reductions over the course of the analysis. The assumptions in this case reflect updated science and analysis, additional cost effective GHG reduction opportunities, and alignment with proposed federal policies. More specifically, these strategies may include but are not limited to reductions in land use change (LUC) adders to CI scores, resumption of flexible fuel vehicle (FFV) manufacturing by OEMs, and relaxation of deliverability requirements for electricity used as a transportation fuel and as a processing fuel. Together, these represent a more expansive market and aggressive outlook for decarbonizing the transportation sector. The assumptions, inputs, and results for the High Case are discussed in the Appendix.

Stakeholder Outreach

ICF retained exclusive decision-making with respect to the parameters that are included in (or excluded from) the modeling in this project. However, as part of the development of our modeling, we sought (and will continue to seek) input and feedback from stakeholders that are uniquely positioned to characterize trends, constraints, and opportunities across various low carbon fuels. ICF conducted interviews with stakeholders representing or from low carbon fuel providers. Through these conversations, ICF introduced the broader project objectives and ICF's modeling approach to help stakeholders understand the key drivers for our analysis. ICF then led a discussion guided by the following questions:

- ***Deployment***. What are expected changes in the industry that will increase or decrease the deployment of a particular fuel or fuel/vehicle combination? These generally include supply and demand considerations and should account for opportunities and barriers to the extent feasible. What is the timeframe associated with any changes?
- ***Carbon intensity.*** What is the current and projected carbon intensity of the fuel under consideration? Are there any California-specific policy or regulatory changes

that can be accommodated to help achieve these reductions? What is the rate at which these carbon intensity changes are likely to occur?

- ***Demand from Other Markets***. Where are the developments likely to occur? Are there any specific advantages or disadvantages associated with delivering these solutions to California that ICF needs to consider? To what extent will other (existing or potential) low carbon fuel markets be advantaged or disadvantaged as it relates to these solutions as a function of their corresponding geography?

Lastly, it is important to note that ICF developed the modeling framework used in this study based on publicly available tools and data—we have purposefully excluded any proprietary data or considerations at this time.

3 Accelerated Decarbonization: Central Case Modeling Inputs

The following sections provide an overview of the key or prioritized inputs that have the most significant impact on the results in the *Central Case* modeled.

Ethanol

Increasing ethanol blended into gasoline: E15

California is a reformulated gasoline market, meaning that about 10% (by volume) of retail gasoline is ethanol to help mitigate air pollutants, and the other 90% of retail gasoline is referred to as California Reformulated Blendstock for Oxygenate Blending (CARBOB). In recent years, increased blends of ethanol in gasoline have gained traction, with the market focused on blending up to 15% (by volume) into gasoline. The U.S. Environmental Protection Agency (EPA) has said that any vehicle with model year 2001 or later can use E15 (in June 2011). In some regions, E15 blending at terminals is halted and E15 retail sales are subsequently halted on June 1. These constraints are imposed during the summer volatility season and relate to elevated Reid Vapor Pressure (RVP). In 2022, the Biden Administration granted a series of emergency waivers that allowed E15 to blended in the summer months; and the Administration has initiated this again, having issued its third waiver for the 2023 summer volatility season in early June. These emergency waivers are designed to help protect consumers from fuel supply constraints under the authority of the Clean Air Act. In 2022, an estimated 1 billion gallons of E15 was sold domestically in 2022.

Despite growth domestically in E15, however, California has not advanced an E15 market because of issues related to a required multimedia evaluation for new additives blended with gasoline. This is changing, however, as the ethanol industry has collaborated with CARB to help advance the consideration of E15 blends in California. Most notably, the Tier 1 report for the required multimedia evaluation was completed and published in June 2020.[2] A follow-on exhaust emissions study was published in June 2022, showing that "ozone forming potential showed a decreasing trend for E15 compared to E10, indicating that the introduction of E15 in the California gasoline market will likely not contribute to increases in ozone formation."[3] ICF anticipates that California will advance towards E15 approval statewide after publication of the Tier 2 and Tier 3 reports associated with the multimedia evaluation, and that this will occur before the end of 2023.

ICF assumes a transition to E15 sales starting in 2024, representing 10% of the California gasoline market and increasing to 90% of the market by 2030. The rate of growth is supported by the potential downward pressure on gasoline pricing that will likely be observed between E15 and E10 blends. For instance, Minnesota reported price differences of up to 30 cents per gallon between E10 and E15 in Summer 2022. Nationally, the EPA estimates that E15 is about 25 cents per gallon cheaper than E10.

The figure below shows ethanol consumption as part of the transition to E15 in our modeling compared to a reference or business as usual case whereby ethanol is limited to E10 blending in gasoline. The black line shows the trajectory for gasoline consumption in California after accounting for ZEV adoption under ACC2 and improved vehicle fuel efficiency. The largest gap between ethanol consumption in our modeled case and the reference case using E10 occurs in 2032 and is about 400 million gallons. Despite the gap in ethanol consumption between the E10 and E15 case, ethanol consumption in California's gasoline market is more or less constant from current levels through 2030 before decreasing in line with gasoline consumption thereafter.

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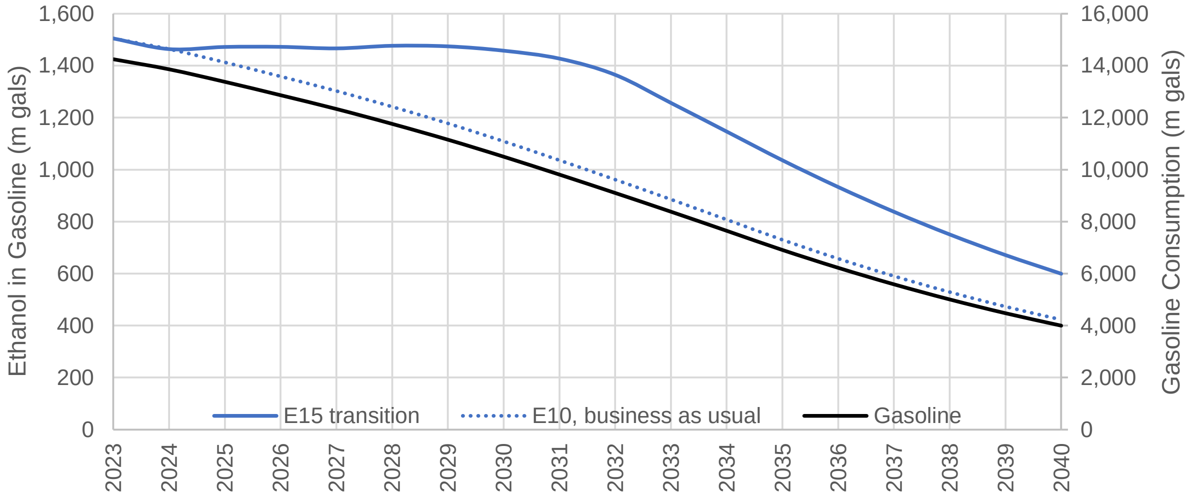
[2] California Multimedia Evaluation of E11-E15 Gasoline-Ethanol Blends Tier I Report, available online here.

[3] Comparison of Exhaust Emissions Between E10 CaRFG and Splash Blended E15, available online here.

Figure 1. Ethanol consumption in gasoline



High level blends of ethanol: E85

Ethanol can also be blended at higher levels with gasoline to make what is referred to as E85, which is generally considered a blend of 85% (by volume) ethanol with 15% gasoline. E85 needs to be consumed in flex fuel vehicles or FFVs. California's population of FFVs has held steady since 2018, with slight increases, despite the reduced availability of new FFVs from automobile manufacturers (OEMs). By the end of 2021, California's FFV population topped about 1.2 million vehicles. Historically, California's FFVs have not consumed much E85; however, in the past several years, the E85 market has shown considerable growth. For instance, in 2022, CARB reports that E85 volumes have increased from around 34 million gallons consumed in 2018 to more than 103 million gallons consumed in 2022.

ICF projected E85 sales volumes as a function of several factors, including the flexible fuel vehicle (FFV) population and a weighted average share of E85 consumption per FFV. E85 volumes exceeded 100 million gallons in 2022, up from around 60 million gallons in 2021. Similarly, FFVs actually increased between 2021 and 2022 in California from about 1.14 million FFVs to 1.21 million FFVs based on data presented by the California Energy Commission (CEC).[4] Based on ICF analysis of average annual fuel consumption of light-duty

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[4] Light-Duty Vehicle Population in California, available online here.

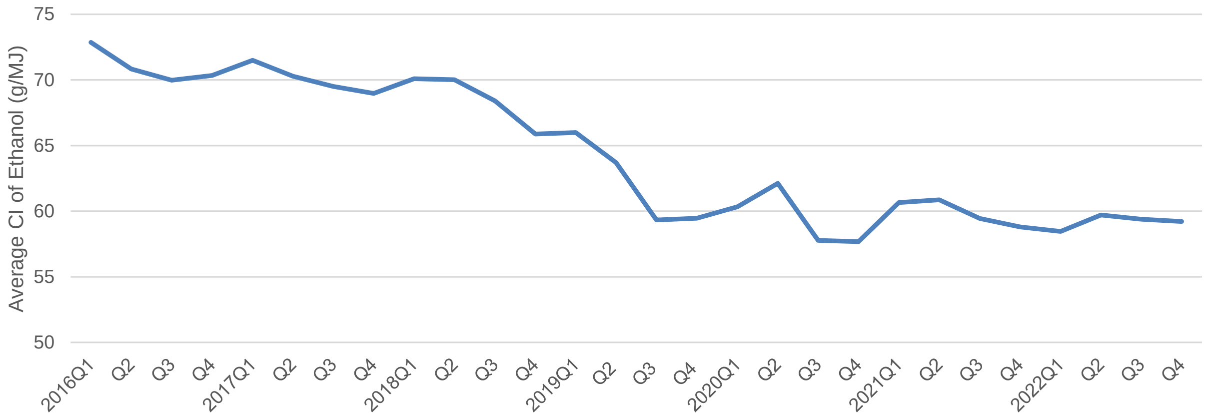
vehicles in California, E85 consumption per vehicle has increased from about 6-8% of average fuel consumption to 16% of average fuel consumption.[5]

ICF increased the FFV fleet by 2.9% annually until 2025 (consistent with the rate of growth observed since OEMs started reducing FFV offerings in their lineups). Starting in 2025, ICF assumed that the FFV fleet would start to shrink as a result of fleet turnover. To forecast the amount of E85 consumed annually, ICF increased the rate of FFV fueling per vehicle to around 50% by 2028 and held it constant thereafter.

CI Reductions for Ethanol

The CI for ethanol has decreased steadily over the course of the LCFS program. It has decreased from around 73 g/MJ in 2016 to just below 60 g/MJ in 2022. These values include the land use change (LUC) adder of 19.8 g/MJ and 11.8 for ethanol from corn and sugarcane, respectively. About 90% of the ethanol in California comes from corn and fiber.

Figure 2. CI of Ethanol in California, 2016-2022



Despite the slower rate of CI improvements for ethanol since 2020, ICF modeled two major changes to the ethanol market with respect to CI: 1) climate smart agriculture and 2) carbon capture and storage (CCS).

Climate Smart Agriculture in this work refers to GHG emission reductions that can be achieved by implementing certain practices during the cultivation and harvesting of feedstocks that are used to produce low carbon transportation fuels. In the case of corn, ICF assumed CI reductions consistent with an analysis that ICF performed for the United

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[5] ICF uses this as a proxy, recognizing that each FFV driver will fuel the vehicle differently with gasoline or E85. The value is calculated as the annual gallons consumed per FFV on the road in the state divided by the average annual fuel consumption for light-duty vehicles in the state. A value of 0% implies that FFVs are fueling exclusively with gasoline, where as a value of 100% implies that all FFVs are consuming E85 all the time.

States Department of Agriculture (USDA)[6] referred to as a high efficiency-high conservation (HEHC) projection of the CI profile of ethanol. That scenario includes CI reductions from the following:

- Domestic farm inputs and fertilizer N_2O: **yield increases** and conservation **technologies and practices**.
- Domestic land use change: **reduced tillage** decreases soil disturbance during field operations and leaves a large proportion of plant residues on the field.
- Fuel production: **process fuel switching** to biomass, **increased corn to ethanol yield**, and other process efficiencies in the ethanol plant**.**

More specifically, ICF incorporated the farm-level adoption of three conservation practice standards (CPSs) in the production of corn used to produce ethanol that USDA's Natural Resources Conservation Service (NRSC) has recognized as having GHG benefits. These are:

- CPS 345—Residue and Tillage Management, Reduced Till;
- CPS 590—Nutrient Management: Improved Nitrogen Fertilizer Management; and
- CPS 340—Cover Crops.

ICF bundled the considerations for CI reductions by a) process efficiencies and b) agronomic practices. For the former, ICF assumed that a 1.2% per year decrease in the CI of ethanol is attributable to process efficiencies during ethanol fuel production. For the latter, ICF assumed that a maximum CI reduction of 21.6% from the baseline ethanol CI could be achieved. For reference, ICF reported that the maximum achievable CI reduction through the implementation of agronomic practices is about 31%.

Ethanol facilities have been targeted for CCS deployment because the purity of the CO2 stream from the fermenters is so high (i.e., 99%). The implementation of CCS at ethanol facilities will reduce the CI of the fuel by around 28 g/MJ. The initial round of CCS investments will focus on ethanol production facilities that have accessibility to geological sequestration in close proximity. For instance, Red Trail Energy in North Dakota began CCS in July 2022, and submitted a design pathway to CARB in 2020. Moving forward, the industry will look to carbon dioxide pipelines for larger-scale CCS. There are several active investments in this space:

- Summit Carbon Solutions is pursuing a project to carry CO2 from over 30 ethanol plants through a 2,000-mile pipeline network to a carbon storage site in North Dakota.

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[6] A Life-Cycle Analysis of the Greenhouse Gas Emissions from Corn-Based Ethanol, available online here.

- Navigator CO2 Ventures (in partnership with Valero and BlackRock) is developing a similar project to transport CO2 from ethanol and fertilizer plants through a 1,300-mile pipeline network to sequestration sites in Illinois.
- Wolf Carbon Solutions has proposed a 350-mile CO2 pipeline project in Iowa.
- Battelle and Catahoula Resources announced in 2021 that they will jointly develop solutions for CCS produced at ethanol facilities in Nebraska.

These proposed facilities will face some challenges due to concerns about CO2 pipeline safety and the sequestration well integrity liability. However, changes to Section 45Q as part of the Inflation Reduction Act (IRA) will help to address these concerns, with changes summarized here:

- The new Section 45Q increased the tax credit value to $85/ton for captured qualified carbon oxide (QCO) stored in geologic formations, $60/metric ton for the use of captured carbon emissions, and $60/metric ton for QCO stored in oil and gas fields if certain wage and apprenticeship requirements are met.
- The IRA expanded eligibility for CCS by extending the beginning of the construction deadline from before January 1, 2026 to before January 1, 2033.
- The IRA lowered the amount of QCO that projects must capture annually to qualify for Section 45Q credits. More specifically, the IRA modifies the definition of "Qualified Facility" under Section 45Q such that the CCS threshold for all eligible facilities is reduced significantly.
- Other changes to Section 45Q relate to the incentive payment and how it can be applied or transferred. The revised Section 45Q now allows for so-called direct pay through a tax refund, which may help project developers avoid the process of raising tax equity. Taxpayers may also elect to transfer Section 45Q credits to an unrelated taxpayer (for cash and are not included in the transferor's income, nor is it deductible by the transferee).

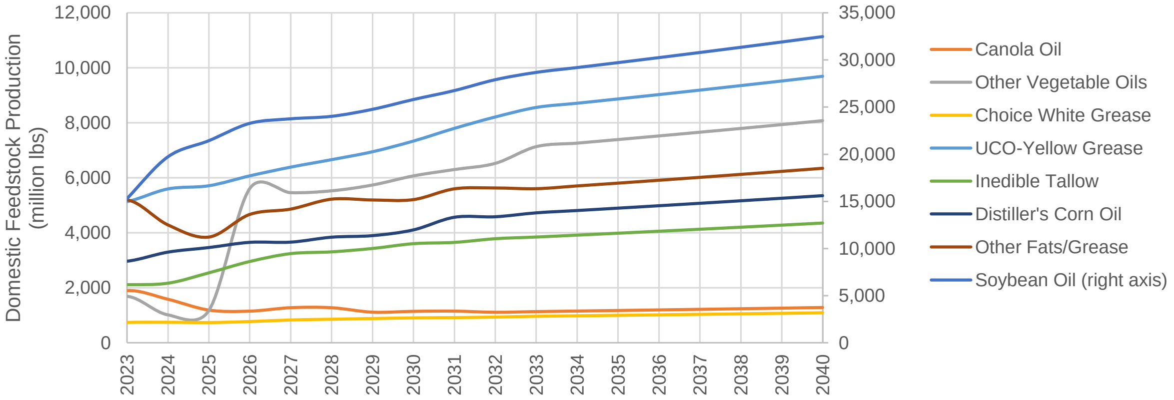
The combination of technological advances made recently, and modifications made to the Section 45Q credits of the Internal Revenue Code, we anticipate that all of the ethanol delivered to California will have incorporated CCS by 2031.

To be clear, the implementation of Climate Smart Agricultural practices and CCS are not mutually exclusive. Considering that, we assessed the market share for ethanol as a transition from "average CI ethanol" in 2022 to a combination of average CI ethanol, climate smart agriculture ethanol, CCS ethanol, and a combination of climate smart agriculture and CCS ethanol over time.

Feedstocks for Liquid Biofuels

The liquid biofuels in subsequent sections--biodiesel, renewable diesel, and renewable jet fuel--depend on similar feedstocks, including soybean oil, canola oil, other vegetable oils, choice white grease, used cooking oil (UCO) or yellow grease, inedible tallow, distiller's corn oil (DCO), and other fats/grease. ICF developed an outlook on the supply of each of these feedstocks in units of million pounds annually. We limited our consideration to domestic feedstocks for the *Accelerated Decarbonization, Central Case*.

Figure 3. Feedstock Availability for Biofuel Production, 2023-2040



We are showing an increase in feedstock availability from a total of about 35 million pounds in 2023 to about 69 million pounds by 2040, a nearly two-fold increase over time.

Biodiesel

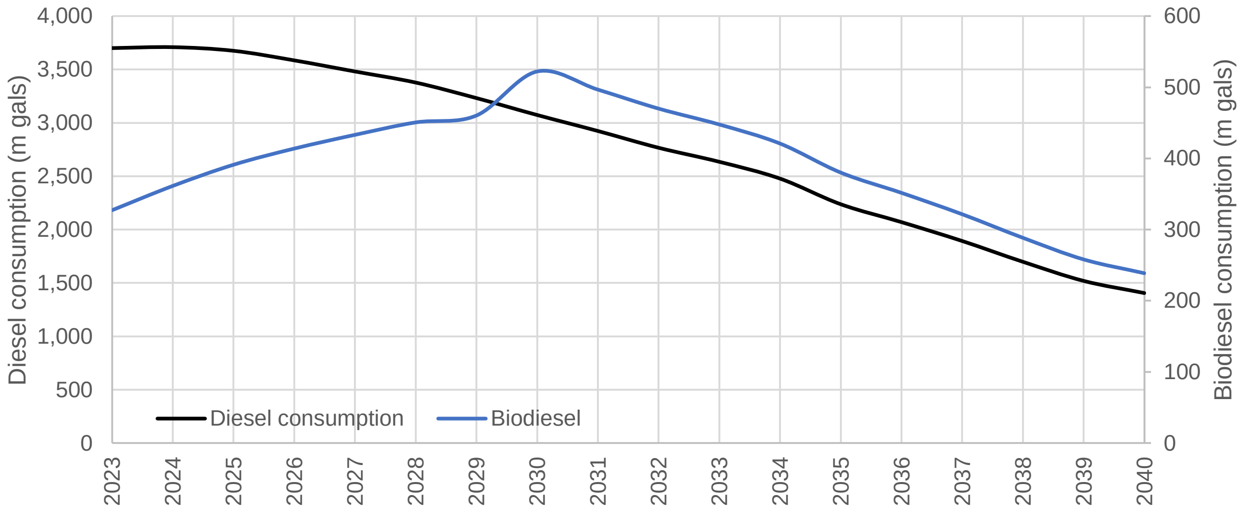
Biodiesel is produced via the processing of virgin oils (e.g., soy or canola), byproducts of other processes (e.g., corn oil extracted via corn ethanol production, and waste products like used cooking oil). Prior to the LCFS program being in place, California consumed very little biodiesel, typically less than 20 million gallons annually. Biodiesel consumption in the program has been aided in part by low CI scores for biodiesel sourced from corn oil, used cooking oil, and tallow. These fuels generally receive CI values less than 25 g/MJ. Other feedstocks include more traditional pathways from virgin oil feedstocks such as soy oil and canola oil. California blended about 290 million gallons of biodiesel in 2021, and 280 million gallons through 2022.

Biodiesel Blending

To date, California's market has hovered around 8% of the diesel pool with less than 15% of the feedstock coming from virgin oils like soybean oil and canola oil. Biodiesel has increased to this higher blend rate following the October 1, 2019 amendment to the California Water Resources Control Board amended California’s Underground Storage Tank (UST) Regulations to reflect diesel containing up to 20% biodiesel, meeting the American Society for Testing and Materials (ASTM) International Standard B20, “shall be recognized as equivalent to diesel for the purpose of complying with existing approval requirements for double-walled USTs, unless any material or component of the UST system has been determined to not be compatible with ASTM B20."

ICF assumed an increase in the blend rate for biodiesel from around 8% in 2022 to as high as 17% by 2030. This blend rate generally aligns with most major engine manufacturers, who warranty their systems up to a 20% blend of biodiesel (by volume) with conventional diesel or B20. The figure below shows the trajectory of biodiesel consumption in California over the modeling period (to 2040) against total diesel consumption; note that diesel consumption is the sum of conventional diesel, renewable diesel, and biodiesel. Biodiesel reaches a peak of about 520 million gallons by 2030 and decreases thereafter as a result of pressure on overall diesel consumption based on regulations like ACT and ACF.

Figure 4. Biodiesel blending in California, 2023-2040



We assumed that the feedstock mix for biodiesel would be similar to what has been observed over the last several years in California, with virgin oil feedstocks representing about 10% of the total volume and waste-based feedstocks like corn oil, tallow, and UCO being the primary feedstocks.

CI Reductions for Biodiesel

We incorporated CI reductions associated with process efficiencies for biodiesel of 1.0-1.2% per year. There is not a detailed analysis available today specific to soybean farming regarding the CI reduction potential from climate smart agricultural practices. In work for the USDA, however, ICF has helped to prioritize areas for further study regarding potential CI reductions for soybean farming, which included reduced and no tillage, cover crops, and conservation crop rotations. Notably, soybean production has a low level of fertilizer application (~25% of acres) as well as a low fertilizer rate (~18 pounds/acre), meaning that improving N fertilization for soybeans will not result in as large of an N_2O reduction as that seen from corn. ICF assumed that the potential reductions from climate smart agricultural practices would yield a reduction of up to 13.5%--we used the combined effects of no tillage and cover crops from ethanol as a proxy for what might be feasible for soybean farming.

Renewable Diesel

Most renewable diesel is produced via the catalytic hydrodeoxygenation of oils (e.g., virgin oils or waste oils) into alkanes and propane, commonly known as hydrotreating or hydrotreated fats and oils (HEFA) processes. This process removes oxygen from the oil, distinguishing it from the traditional trans-esterified fatty acid methyl-ester (FAME) biodiesel. Most producers use a catalytic isomerization technique to improve the stability of renewable diesel, specifically to adjust the cloud point to avoid any problems during operation in cold weather. Renewable diesel is functionally equivalent to conventional diesel, and as such requires no modification or special precautions for the engine.

California consumed approximately 385 million and 620 million gallons of renewable diesel in 2018 and 2019, respectively, representing a 60% increase year-over-year. We note growth in 2020 was expected to continue prior to the pandemic; however, 2020 ended up at 659 million gallons due to reduced demand associated with the lockdowns. 2021 was another strong year with 941 million gallons reported, and California consumed 1.39 billion gallons of renewable diesel in 2022.

Renewable diesel has garnered the most significant amount of investment from the refining industry over the past 24 months, as evidenced by the planned expansions and announced projects highlighted below, represent as much as 6.5 billion gallons of new renewable diesel supply coming online in the next 12-24 months.

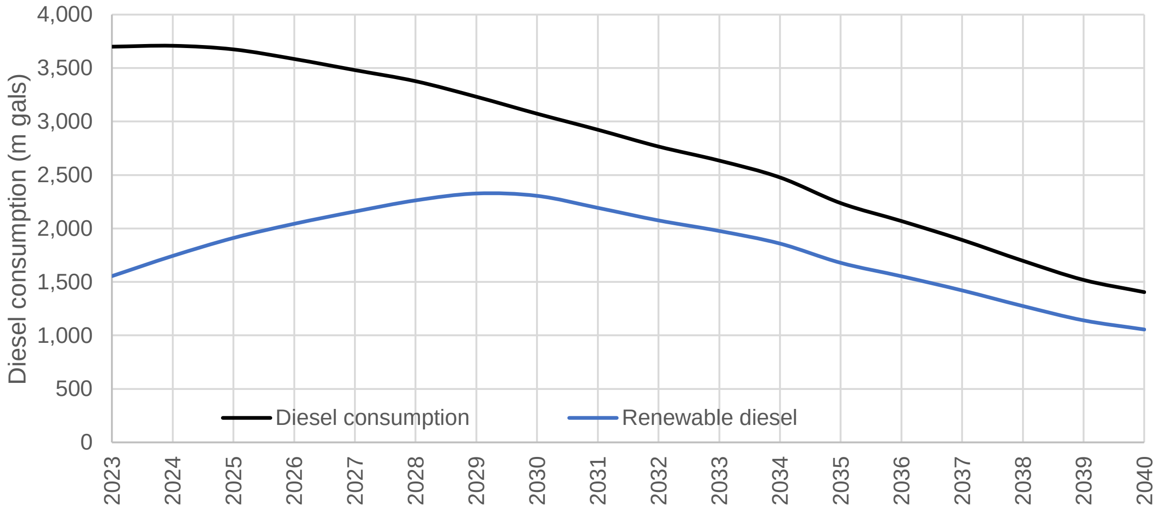
Project	Location	Capacity MMGPY	Type	Announced Operation Date
Martinez Renewables	Martinez, CA	250	Conversion	2023
REG Geismar	Geismar, LA	50	Expansion	2023
Global Clean Energy	Bakersfield, CA	220	Conversion	2023
Vertex	Mobile, AL	180	Conversion	2023
BP Cherry Point Ex 1	Washington	100	Expansion	2023
Chevron	El Segundo, CA	125	Conversion	2023
Kern Oil and Refining	Bakersfield, CA	150	Conversion	2023
PBF Chalmette	Chalmette, LA	150	Conversion	2023
Tidewater	Prince George, BC	180	Conversion	2023
Calumet	Great Falls, MT	184	Conversion	2023
P66	Rodeo, CA	680	Conversion	2024
Martinez Renewables	Martinez, CA	450	Expansion	2024

Project	Location	Capacity MMGPY	Type	Announced Operation Date
Gron Fuels	Port Allen, LA	890	Green field	2024
Love's	Hastings, NE	80	Conversion	2024
Diamond Green	Norco, LA	400	Expansion	2024
World Energy, AltAir	Paramount, LA	290	Expansion	2025
World Energy	Houston, TX	125	Conversion	2025
Fulcrum Bioenergy	Gary, IN	31	Green field	2025
NEXT Renewable	Oregon	600	Green field	Unknown
PBF Chalmette	Chalmette, LA	150	Expansion	Unknown
ReadiFuels Iowa	Sioux Center, IA	35	NA	Unknown
Emerald Biofuels	Texas	110	Green field	Unknown
DG Fuels	St. James Parish, LA	151	DG Fuels	Unknown
CVR Energy	Coffeyville, KS	1450	Conversion	Unknown
Covenant Energy	Saskatchewan, CN	100	Green field	Unknown
Ceres Global Ag	Saskatchewan, CN	144	Green field	Unknown

The presence of commercial facilities operating Honeywell UOP's, Haldor Topsoe, and other commercially available renewable diesel technologies has helped bolster the likelihood of various commercial commitments and has bolstered market confidence in the engineering and production capabilities of these actors.

ICF forecasted renewable diesel production in North America, and considered demand from other low carbon fuel markets, including via Oregon, Washington, British Columbia, and Canada. Our renewable diesel outlook for California is a bottoms-up estimate based on announced facilities. For each facility, ICF assigns a probability of the facility coming online, the probability of delivering fuel to California, and the mix of feedstocks to be used at the facility. The supply for feedstocks is constrained separately (as noted previously).

Figure 5. Renewable diesel blending in California, 2023-2040



We did impose an arbitrary constraint on the renewable diesel distribution to California in the Central Case, with it not exceeding 75% of the diesel market. In other words, by around 2030, 75% of the diesel market is renewable diesel, 17% is biodiesel, and the balance is conventional diesel. Similar to biodiesel, renewable diesel consumption peaks in 2030 as diesel consumption faces downward pressure from regulations like ACT and ACF in California. Renewable diesel consumption in California in ICF modeling peaks at 2.3 billion gallons in 2030, which is a fraction of what is expected to come online over the next several years. Based on our review of project announcements and feedstock supply, and considerations of moving product into California, we assumed that virgin oils would comprise about 30-33% of the total renewable diesel market in California.

CI Reductions for Renewable Diesel

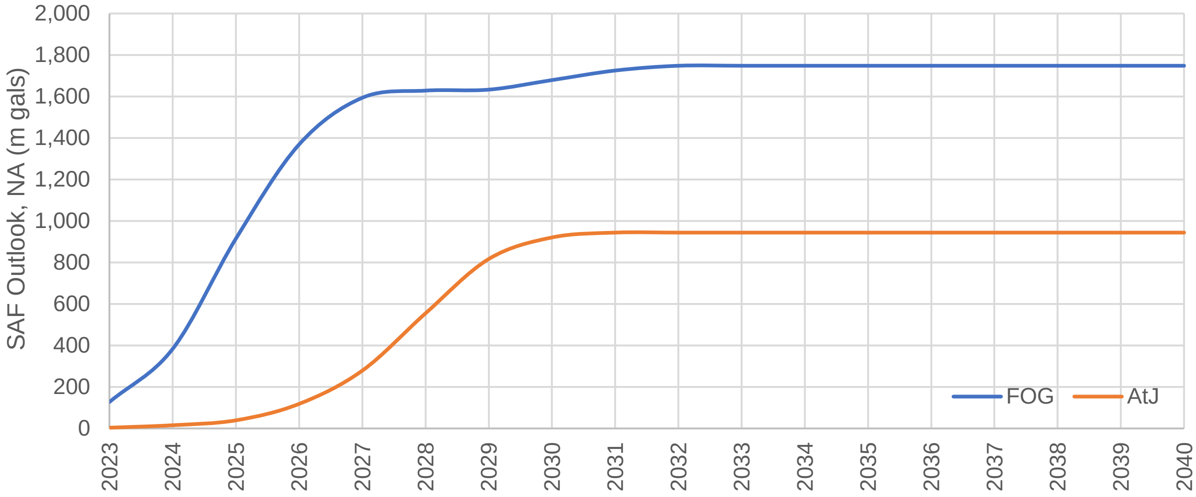
The CI reductions for renewable diesel are implemented in the same way as those that are reported for biodiesel. We incorporated CI reductions associated with process efficiencies for renewable diesel of 1.0-1.2% per year. ICF assumed that the potential reductions from climate smart agricultural practices for the subset of the renewable diesel product that is tied to virgin oils like soybean oil would yield a reduction of up to 13.5%--we used the combined effects of no tillage and cover crops from ethanol as a proxy for what might be feasible for soybean farming.

Renewable Jet Fuel

Renewable jet fuel (or alternative jet fuel or sustainable aviation fuel, SAF) became eligible to generate LCFS credits in 2019. In 2022, nearly 12 million gallons of renewable jet fuel were blended into California's jet fuel supply.

ICF forecasted intrastate jet fuel demand outlook for California assuming about 450 million gallons per year of consumption, growing at an annualized rate of about 1% before plateauing in 2030 at around 510 million gallons. This may be a conservative estimate considering that CARB may have the jurisdictional authority to subject all fossil jet fuel sold in California to the LCFS program. For the sake of simplicity, we assumed that CARB will regulate conventional jet fuel using the same CI reduction schedule as for gasoline and diesel moving forward.

ICF tracks renewable jet fuel announcements and differentiates them between two production pathways: via hydroprocessed esters and fatty acids (HEFA) or via alcohol-to-jet (ATJ) pathways. Both of these pathways are being pursued actively by producers today. The figure below shows our current outlook for North America production of renewable jet fuel or SAF from 2023 to 2040 for HEFA processing of fats, oils, and greases (FOG) and for ATJ pathways.



SAF investments are driven by a variety of factors, including incentives in the IRA and targets established via the federal government.

CI Reductions for Renewable Jet Fuel

The CI reductions for renewable jet fuel via HEFA pathways are implemented in the same way as those that are reported for biodiesel and renewable diesel. We incorporated CI reductions associated with process efficiencies for renewable jet fuel of 1.0-1.2% per year. ICF assumed that the potential reductions from climate smart agricultural practices for the subset of the renewable diesel product that is tied to virgin oils like soybean oil would yield a reduction of up to 13.5%--we used the combined effects of no tillage and cover crops from ethanol as a proxy for what might be feasible for soybean farming.

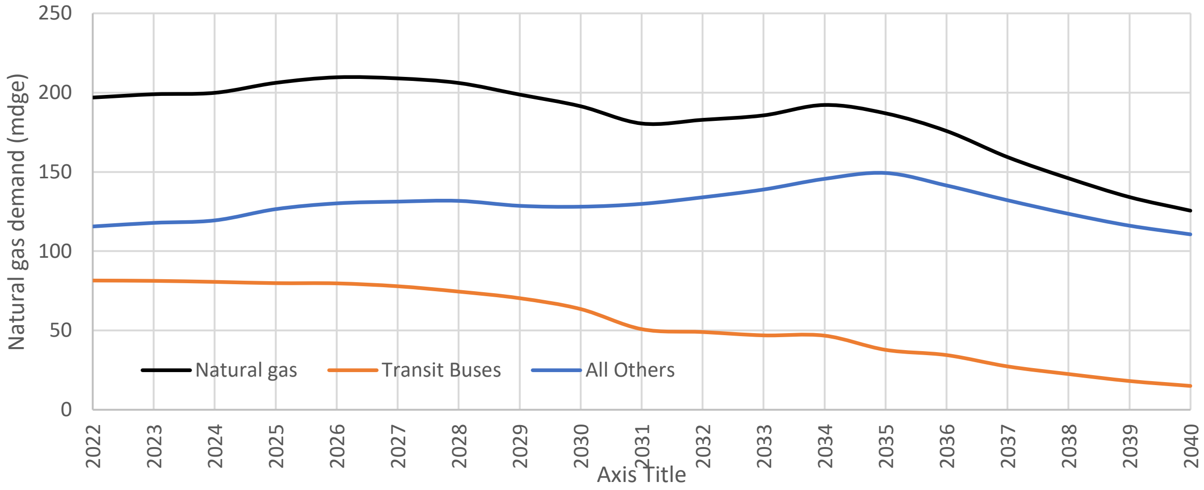
The CI reductions for renewable jet fuel via ATJ pathways are implemented in the same way as those that are reported for ethanol, with the assumption that the same ethanol that is used for blending into gasoline is also to be used for SAF.

Natural Gas Demand and NGV Deployment

Natural gas use as a transportation fuel reached about 200 million diesel gallons equivalent (mdge) in 2022, with 96.5% of the product being renewable natural gas (RNG) and just 3.5% of the total volume coming from fossil natural gas.

Forecasting natural gas vehicle (NGV) deployment requires modifications to EMFAC2021. For instance, EMFAC2021 reports about 160 mdge of natural gas consumed in the transportation sector for 2022, well below the 200 mdge actually consumed. ICF made no changes to the rate of decline in the consumption of natural gas as a transportation fuel used in transit buses, as this decrease is tied to ICT compliance. After accounting for ACF compliance, ICF assumed in the Central Case that for every heavy-duty truck that is not subject to ACF that there is a 15% chance to convert that vehicle to an NGV. By ICF's estimate, this will increase NGV deployment by about 1,800 and 3,000 in 2025 and 2027, respectively, compared to default ACF modeling.

Figure 6. Natural Gas Demand, 2023-2040



Biogas | Renewable Natural Gas

Most of the RNG that is currently produced is used as a transportation fuel. Furthermore, most of the RNG used in the transportation industry is derived from landfills. However, California's market is shifting towards lower carbon intensity RNG from feedstocks such as the anaerobic digestion of animal manure and from digesters deployed at waste water treatment plants or water resource recovery facilities (WRRFs). Over time, these lower carbon sources will likely displace substantial volumes of higher carbon intensity RNG from landfills; however, these alternative sources of RNG tend to have smaller production profiles and will not be able to displace landfill gas entirely in the system.

By the end of 2022, for instance, 49% of RNG consumed in California was from lower CI sources, and most of that was from animal manure (making up 46% of the total). Moving forward, however, ICF modeled two key aspects for RNG: 1) The California market will be saturated with low CI RNG in the next 2-3 years, and 2) that because of incentives in the IRA, greater optionality for biogas in the transportation market will materialize.

With respect to the latter, ICF's modeling provides optionality with respect to the deployment of biogas as a resource to produce three fuels: renewable natural gas, electricity, or hydrogen. Furthermore, ICF modeling enables each of these fuels to be used as a transportation fuel (e.g., biogas to electricity used in an electric vehicle) *or* as a process fuel in the production of other low carbon fuels (e.g., renewable natural gas into a SMR unit to make green hydrogen that is used in renewable diesel production). Our modeling is neither deterministic nor optimized related to biogas use. The challenge with either of these approaches is that they both imply a certainty associated with the best use of the fuel based on some condition imposed by the model e.g., cost. The uncertainty of the value associated with the "best use" of biogas makes for a challenging modeling exercise, and requires consideration of federal tax incentives (e.g., via the Inflation Reduction Act, most of which lack guidance that would be needed to optimize around cost), as well as various physical and environmental commodity streams (e.g., RINs). ICF is working with stakeholders to develop a loading order for biogas--this our best attempt to highlight the flexibility of the resource, while also recognizing that certain uses will have higher value than others, and that different production pathways have different project economics.

ICF has provided a biogas supply estimate across two geographies--California and the rest of the United State-- and 8 feedstocks that we assume are used to generate fuel via either anaerobic digestion or thermal gasification (noting that the latter is also a pathway for woody biomass to liquid biofuels in our modeling). The feedstocks included landfill gas (LFG), animal manure, wastewater facilities, food waste, agricultural residues, forest products and forestry residues, energy crops, and municipal solid waste (MSW).

ICF developed three supply outlooks--a lower bound, upper bound, and maximum achievable. We used the same approach as part of work for the Michigan Public Service Commission (MPSC).[7] We estimate the resource potential scenarios by considering constraints unique to each potential biogas feedstock, these constraints are based on

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[7] Michigan Renewable Natural Gas Study, September 2022. Available online here.

factors such as feedstock accessibility. ICF's resource assessment is conducted using a combination of national-, state-, and regional-level information regarding the availability of different feedstocks.

ICF estimates approximately 870-1,210 trillion Btu (tBtu) of biogas can be captured annually for processing into useful energy by 2030 in the lower and upper bound scenarios, with about 100-137tBtu of this biogas sourced from California.

The biogas feedstocks and associated utilization assumed is highlighted in the following subsections.

Landfill Gas

To develop the biogas potential from LFG, ICF extracted data from the Landfill Methane Outreach Program (LMOP) administered by the U.S. EPA, which included more than 2,000 landfills included in the inventory. Due to the minimal and declining methane production of waste after 25 years in landfills, in building the scenarios ICF considered only landfills that are either open or were closed post-2005. This reduced the number of landfills included in our analysis.

ICF developed assumptions for the resource potentials for biogas production at landfills in the two scenarios, considering the potential at LFG facilities with collection systems in place, LFG facilities that do not have collection systems in place, and candidate landfills identified by the U.S. EPA.

- In the Lower Bound, ICF assumed that 75% of eligible LFG facilities would produce biogas.
- In the Upper Bound, ICF assumed that 95% of eligible LFG facilities would produce biogas.

Animal Manure

ICF considered animal manure from a variety of animal populations, including beef and dairy cows, broiler chickens, layer chickens, turkeys, and swine. Animal populations were derived from the United States Department of Agriculture's (USDA) National Agricultural Statistics Service. ICF used information provided from the most recent census year (2017) and extracted total animal populations on a county and state level.[8] ICF developed the biogas potential using animal manure production and the energy content of dried manure taken from a California Energy Commission report prepared by the California Biomass

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[8] USDA, 2017. 2017 Census of Agriculture, https://www.nass.usda.gov/AgCensus/index.php

Collaborative.[9] These inputs are summarized in Table 1 below, with the formula and an example calculation of a 10,000-head dairy farm included for reference:

$$number\ of\ livestock\ \times volatile\ solids\ \times heating\ value\ = biogas\ production\ potential$$

$$10{,}000\ head\ \times 3{,}020\ \frac{kg\ (dry)}{head} \times 16{,}111\ \frac{Btu}{kg\ (dry)} \times \frac{1}{1.0^6} = 486{,}491\ MMBtu$$

Table 1. Key Parameters for Animal Manure Resource Biogas Potential

Animal Type	Volatile Solids (kg/head/yr)	HHV (Btu/kg, dry basis)
Dairy	3,020	16,111
Beef:		
- Cattle	1,674	16,345
- Other	750	16,345
Swine	149	15,077
Poultry:		
- Layer Chickens	8.3	14,689
- Broiler Chickens	9.1	15,077
- Turkeys	25.0	14,830
Sheep & Goats	242	9,362

The animal manure inventory does not identify specific facilities or locations where biogas will likely be produced. However, concentrated animal feeding operations (CAFOs) provide an indication of where biogas from animal manure could be produced. The existing accumulation of animal manure at CAFOs located near pipeline infrastructure could conceivably increase the productive potential of animal manure as a biogas feedstock. ICF developed the following assumptions for the resource potentials for biogas production from animal manure in the two scenarios:

- In the Lower Bound, ICF assumed that 30% of the animal manure would be used to produce biogas.
- In the Upper Bound, ICF assumed that 60% of the animal manure would be used to produce biogas.

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[9] Williams, R. B., B. M. Jenkins and S. Kaffka (California Biomass Collaborative). 2015. An Assessment of Biomass Resources in California, 2013 – DRAFT. Contractor Report to the California Energy Commission. PIER Contract 500-11-020. Available online here.

Wastewater Facilities

To determine biogas potential from wastewater facilities or water resource and recovery facilities (WRRFs), ICF used the Clean Watersheds Needs Survey (CWNS) conducted in 2012 by the U.S. EPA, an assessment of capital investment needed for wastewater collection and treatment facilities to meet the water quality goals of the Clean Water Act and includes more than 14,500 WRRFs. ICF distinguishes between facilities based on location and facility size as a measure of average flow (in units of million gallons per day, MGD). ICF also reviewed more than 1,200 facilities that are reported to have anaerobic digesters in place, as reported by the Water Environment Federation.

To estimate the amount of biogas produced from wastewater at WRRFs, ICF used data reported by the U.S. EPA,[10] a study of WRRFs in New York State,[11] and previous work published by AGF.[12] ICF used an average energy yield of 7.003 MMBtu/MG of wastewater.

ICF developed the following assumptions for the resource potentials for biogas production at WRRFs in the two scenarios:

- In the Lower Bound, ICF assumed that 80% of the WRRFs with a capacity greater than 7 MGD would produce biogas.
- In the Upper Bound, ICF assumed that 90% of the WRRFs with a capacity greater than 3.5 MGD would produce biogas.

Food Waste

Food waste is a major component of MSW—accounting for about 15% of MSW streams. More than 75% of food waste is landfilled. Food waste can be diverted from landfills to a composting or processing facility where it can be treated in an anaerobic digester. ICF limited our consideration to the potential for utilizing the food waste that is currently landfilled as a feedstock for biogas production via AD, thereby excluding the 25% of food waste that is recycled or directed to waste-to-energy facilities. In addition, food waste that is potentially diverted from landfills in the future is not included in the landfill gas analysis, thereby avoiding any issues around double counting of biomass from food waste.

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[10] US EPA, Opportunities for Combined Heat and Power at Wastewater Treatment Facilities, October 2011. Available online here.

[11] Wightman, J and Woodbury, P., Current and Potential Methane Production for Electricity and Heat from New York State Wastewater Treatment Plants, New York State Water Resources Institute at Cornell University. Available online here.

[12] AGF, The Potential for Renewable Gas: Biogas Derived from Biomass Feedstocks and Upgraded to Pipeline Quality, September 2011.

ICF extracted county-level information from the U.S. DOE's Bioenergy Knowledge Discovery Framework (KDF), which includes information collected as part of U.S. DOE's Billion Ton Report (updated in 2016). The Bioenergy KDF includes food waste at tipping fee price points ranging from $70/ton to $100/ton. ICF assumed a high heating value of 12.04 MMBtu/ton (dry). Note that the values from the Bioenergy KDF are reported in dry tons, so the moisture content of the food waste has already been accounted for in the DOE's resource assessment.

ICF developed the following assumptions for the biogas production potential from food waste in the two scenarios:

- In the Lower Bound scenario, ICF assumed that 80% of available food waste would be diverted to AD systems for biogas production.
- In the Upper Bound, ICF assumed that 95% of available food waste would be diverted to AD systems for biogas production.

Agricultural Residue

Agricultural residues include the material left in the field, orchard, vineyard, or other agricultural setting after a crop has been harvested. More specifically, this resource is inclusive of the unusable portion of crop, stalks, stems, leaves, branches, and seed pods. Agricultural residues (and sometimes crops) are often added to anaerobic digesters.

ICF extracted information from the U.S. DOE Bioenergy KDF, including corn stover, noncitrus residues, tree nut residues, and wheat straw. These estimates are based on modeling undertaken as part of the 2016 Billion Ton Study, and utilizes the Policy Analysis System (POLYSYS), a policy simulation model of the U.S. agricultural sector. The POLYSYS modeling framework simulates how commodity markets balance supply and demand via price adjustments based on known economic relationships and is intended to reflect how agricultural producers respond to new and different agricultural market opportunities, such as for biomass. Available biomass is constrained to not exceed the tolerable soil loss limit of the USDA Natural Resources Conservation Service and to not allow long-term reduction of soil organic carbon.

ICF developed the following assumptions for the biogas production potential from agricultural residues in the two scenarios.

- In the Lower Bound, ICF assumed that 20% of the agricultural residues available at $40/dry ton would be diverted to biogas production.
- In the Upper Bound, ICF assumed 70% of the agricultural residues available at $60/dry ton would be diverted to biogas production.

Forestry and Forest Product Residues

Forestry and forest product residues include biomass generated from logging, forest and fire management activities, and milling. Logging residues (e.g., bark, stems, leaves, branches), forest thinnings (e.g., removal of small trees to reduce fire danger), and mill residues (e.g., slabs, edgings, trimmings, sawdust) are also considered in the analysis. This includes materials from public forestlands (e.g., state, federal), but not specially designated forests (e.g., roadless areas, national parks, wilderness areas) and includes sustainable harvesting criteria as described in the U.S. DOE Billion Ton Update. The updated DOE Billion Ton study was altered to include additional sustainability criteria. Some of the changes included:[13]

- Alterations to the biomass retention levels by slope class (e.g., slopes with between 40% and 80% grade included 40% biomass left on-site, compared to the standard 30%).
- Removal of reserved (e.g., wild and scenic rivers, wilderness areas, USFS special interest areas, national parks) and roadless designated forestlands, forests on steep slopes and in wet land areas (e.g., stream management zones), and sites requiring cable systems.
- The assumptions only include thinnings for over-stocked stands and did not include removals greater than the anticipated forest growth in a state.
- No road building greater than 0.5 miles.

These additional sustainability criteria provide a more realistic assessment of available forestland than other studies.

ICF extracted information from the U.S. DOE Bioenergy KDF, including information on forest residues such as thinnings, mill residues, and different residues from woods (e.g., mixedwood, hardwood, and softwood). The Bioenergy KDF estimates are based on ForSEAM, a linear programming model constructed to estimate forestland production over time, developing both traditional forest products but also products that meet biomass feedstock demands. The model assumes that projected traditional timber demands will be met and estimates costs, land use, and competition between lands. The forestry and forest product residue estimates also reflect a cost minimization framework that minimizes the total costs (harvest costs and other costs) under a production target goal in addition to land, growth, and other constraints. The cost minimization framework incorporates the

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[13] DOE, 2011. *2011 Billion Ton Update – Assumptions and Implications Involving Forest Resources*, http://web.ornl.gov/sci/ees/cbes/workshops/Stokes_B.pdf

POLYSYS model as well as IMPLAN, an input-output model that estimates impacts to the economy.[14]

ICF extracted data from the Bioenergy KDF at price points, from $30/ton to $100/ton, although the price points did not show any variation in production potential for forest and forest product residue biomass from 2025 out to 2040. ICF developed the following assumptions for the biogas production potential from forest residues in the two scenarios:

- In the Lower Bound, ICF assumed that 20% of the forest and forestry product residues available at $40/dry ton would be diverted to biogas production.
- In the Upper Bound, ICF assumed that 70% of the forest and forestry product residues available at $60/dry ton would be diverted to biogas production.

Energy Crops

Energy crops are inclusive of perennial grasses, trees, and some annual crops that can be grown specifically to supply large volumes of uniform, consistent quality feedstocks for energy production. Energy crop estimates are based on the same modeling framework used to derive the agricultural residue estimates, outlined in the previous section. With respect to land use, rather than shifting existing agricultural production (e.g., corn and soy) to energy crop production, DOE's modeling also shows that energy crops are largely grown on idle or available pasture lands, particularly at lower farmgate prices. Similar to agricultural residues, in the simulations no land use change is assumed to occur, except within the agricultural sector (i.e., forested land is not converted to agricultural land for agricultural residue or energy crop purposes).

ICF extracted data from the Bioenergy KDF at $10 price point increments, from $30/ton to $100/ton that showed variation in production potential for energy crops from 2025 out to 2040. ICF developed assumptions for the biogas production potential from energy crops for the two scenarios:

- In the Lower Bound, ICF assumed that 20% of the energy crops available outside of California at $40/dry ton would be diverted to biogas production.
- In the Upper Bound, ICF assumed that 40% of the energy crops available outside of California at $60/dry ton would be diverted to biogas production.

Municipal Solid Waste

MSW represents the trash and various items that household, commercial, and industrial consumers throw away—including materials such as glass, construction and demolition (C&D) debris, food waste, paper and paperboard, plastics, rubber and leather, textiles,

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[14] DOE, 2016. 2016 Billion Ton Report, https://www.energy.gov/eere/bioenergy/2016-billion-ton-report

wood, and yard trimmings. About 25% of MSW is currently recycled, 9% is composted, and 13% is combusted for energy recovery, with the remaining balance (about 50%) landfilled.

ICF limited consideration to biogenic MSW types not covered in other feedstock categories – paper and paperboard, and yard trimmings. We further limited MSW to only the potential for utilizing MSW that is currently landfilled as a feedstock for thermal gasification; this excludes MSW that is recycled or directed to waste-to-energy facilities.

ICF extracted information from the U.S. DOE's Bioenergy KDF, which includes information collected as part of U.S. DOE's Billion Ton Report (updated in 2016). The Bioenergy KDF includes the following waste residues: construction and demolition (C&D) debris, paper and paperboard, plastics, rubber and leather, textiles, wood, yard trimmings, and other. ICF extracted data from the Bioenergy KDF at price points between $30/ton and $60/ton. ICF developed assumptions for the biogas production potential from MSW for the two scenarios:

- In the Lower Bound, ICF assumed that 20% of the MSW available at $40/dry ton would be diverted to biogas production.
- In the Upper Bound, ICF assumed that 70% of the MSW available at $60/dry ton would be diverted to biogas production.

Battery Electric Vehicles & Fuel Cell Electric Vehicles

The publicly available version of EMFAC accounts for the ACT and ICT Rules, which together drive electrification (whether it be through electricity or hydrogen) in heavy-duty market segments. ICF modified the EMFAC model to account for compliance with the ACC2 Advanced Clean Fleets (ACF) rule.

Advanced Clean Cars 2.0 Modeling for Light-duty Market Segments

ICF modeling of ACC2 requirements relies on CARB's rulemaking documents and up-to-date market data. EMFAC2021 is used as the basis to estimate new sales, vehicle population, and fuel and energy consumption. EMFAC2021 uses vehicle registration from the California Department of Motor Vehicles (DMV) through 2019 and projects ZEVs based on consumer choice modeling approach[15]. To forecast the impacts of ACC2 on EV new sales and EV population on road, the following assumptions are made:

- New vehicle sales by calendar year are estimated as 1.25x the population of vehicles with age equal to zero derived from EMFAC2021, as EMFAC uses an October cut of

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[15] California Air Resources Board (CARB) (2021). EMFAC2021 Technical Document. Available at: https://ww2.arb.ca.gov/sites/default/files/2021-08/emfac2021_technical_documentation_april2021.pdf

DMV data and may miss the new vehicle registrations in the last quarter of each year.

- EV fractional share, including battery electric vehicles (BEVs), fuel cell electric vehicles (FCEVs), and plug-in hybrid electric vehicles (PHEVs), of new sales in 2020 and 2021 is based on CARB's adjusted baseline in the Initial Statement of Reasons (ISOR)[16], while the fractions from 2023 to 2025 are interpolation between CEC's report in 2022 and ACC2 requirements in 2026 and also align with 2021 Annual Alternative Fuel Survey Results published by CARB.
- To comply with ACC2, annual EV requirements start with 35% of new vehicles sales in 2026 and continue to ramp up quickly to nearly 70% by 2030 and reaches 100% in 2035.
- The splits among BEVs, PHEVs, and FCEVs relies on CARB's modeling of emission benefit analysis.

Advanced Clean Fleet Modeling for Heavy-duty Market Segments

ICF modeling of the ACF regulation mainly followed the same assumptions as stated in CARB's rule-making documents, including the total affected population, ZEV purchase and phase-in schedule, statutory useful life assumptions, etc.[17] ICF considered all four components as required by the rule:

- State and local agencies: ICF modeled that 50 percent of vehicle purchases made by state and local government fleets are ZEVs beginning in 2024 and 100 percent of vehicle purchases are ZEVs by 2027.
- Drayage fleets: ICF assumed that any truck that is 15 years or older would be subject to the useful life requirement of ACF and be removed from the drayage inventory. Any new addition to the inventory will be ZEV starting in 2024.
- High priority and federal fleets: ICF assumed that all the regulated fleets would follow the ZEV Milestones Option and meet ZEV targets as a percentage of the total fleet starting with vehicle types that are most suitable for electrification.
- Manufacturer sales mandate: ICF modeled that all in-state sales of Class 2b-8 vehicles will be zero-emission starting in 2036.

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[16] California Air Resources Board (CARB) (2022). Public Hearing to Consider the Proposed Advanced Clean Cars II Regulations. Staff Report: Initial Statement of Reasons. Available at: https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/accii/isor.pdf

[17] California Air Resources Board (CARB), Advanced Clean Fleets Regulation: Appendix F. Emissions Inventory and Results, available at https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/acf22/appf.pdf

In addition, ICF modeling also considered the new provision to leave more time for CNG trucks supporting waste diversion and biomethane production.[18] The technology mix projections also stayed consistent with CARB's assumptions that 10 percent of day cab tractors would be FCEV until 2027 and 25 percent afterwards, and an even 50:50 split between BEVs and FCEVs for sleeper cabs. For all other vehicles, all ZEVs would be battery-electric until 2026, and purchases starting in 2027 onward would be 90 percent BEV and 10 percent FCEV.[19] For modeling simplicity, ICF assumed that all instate tractors are day cabs, while interstate and out-of-state Class 8 tractors[20] are sleeper cabs.

Carbon Intensity for Electricity

ICF developed CI trajectories for four types of electricity considered in our analysis, including grid average electricity, zero carbon intensity electricity using book-and-claim provisions, LFG-to-electricity, and dairy biogas-to-electricity. The CI values for the latter three are held constant over the course of the analysis but have increasing market shares over time. The grid average CI is decreased in line with the Renewable Portfolio Standard (RPS) requirements (e.g., 60% RPS by 2030) using a straight-line decrease from 2023 to 2030. ICF assumed that the grid would be decarbonized at the same rate post-2030, reaching 32 g/MJ by 2040.

Carbon Intensity for Hydrogen

ICF developed CI trajectories for four types of hydrogen considered in our analysis, including SMR from fossil gas, RNG from LFG, or RNG from animal manure, and via electrolysis using renewable electricity. These are each held constant over the course of the analysis but have varying shares of the market over time.

Summary of Factors Not Considered in ICF Modeling

ICF did not consider several factors that impact the supply-demand balance of credits and deficits because our modeling exercise is focused on the carbon intensity reductions that could be achieved, rather than optimizing some compliance outlook via scenario modeling. For instance, we did not consider:

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[18] One of the five new provisions introduced to the Board in the latest April 2023 hearing, more information available at https://ww2.arb.ca.gov/sites/default/files/barcu/board/books/2023/042723/23-4-2pres.pdf

[19] California Air Resources Board (CARB), Advanced Clean Fleets Regulation Staff Report: Initial Statement of Reasons, available at https://ww2.arb.ca.gov/sites/default/files/barcu/regact/2022/acf22/isor2.pdf

[20] T7 CAIRP, T7 NOOS, and T7 NNOOS categories under EMFAC2021

- *Off-road electrification*. There are several technologies that generate credits in off-road applications, including fixed guideway systems, electric forklifts, cargo handling equipment, shore power for ocean going vessels, and truck refrigeration units. Together, these technologies generated about 2.2 million credits in 2022. Most of those credits (1.5 million credits) are tied to electricity used in forklifts, and CARB has proposed a variety of ways to modify reporting requirements for electric forklifts that will likely decrease credit generation substantially. Given the uncertainty around some of these markets, the Central Case excludes consideration of these technologies for the sake of simplicity. These credit generating pathways are considered in the High Case (see the Appendix: Accelerated Decarbonization in the High Case).
- *Infrastructure crediting*. Credits can be generated from DC fast charging and deploying hydrogen refueling infrastructure. CARB staff have also proposed modifying and expanding these credit generation pathways to medium- and heavy-duty vehicles. We did not consider these credits in our Central Case; however, these are considered in the High Case (see the Appendix: Accelerated Decarbonization in the High Case).
- *Incremental deficits*. CARB calculates and posts annually the crude average carbon intensity of crude refined at California refineries or refineries that distribute fuel to California. The value is reported on a three-year average basis. If the three-year average is greater than California Baseline Crude Average CI of 11.85 g/MJ plus 0.1 g/MJ, then all gallons of gasoline and diesel sold in California are subject to incremental deficits. In 2022, about 1.6 million incremental deficits were reported for gasoline (CARBOB) and diesel. It is unclear to what extent this will impact deficit generation in the future, but given the three-year rolling basis, we anticipate it will likely have an impact at least through 2025. However, ICF did not account for this in our modeling.

Generally, we believe that the eligible credit generating pathways and deficit generating aspects of the program that we did not consider in the Central Case lean towards slightly *higher* credit generation than considered in our analysis.

4 Summary of Results

ICF modeling shows that the lifecycle GHG emissions for the transportation sector (including gasoline, diesel, and intrastate jet fuel) can decrease by 42% by 2030 and 77% by 2040 from 2010 values.

Table 2. Lifecycle GHG Emissions in California's Transportation Sector

Lifecycle GHG emissions MMT CO2e	**2010**	**2030**	**2040**
Transportation fuels	222	128	51

% Reduction	--	42%	77%

ICF overlaid the results of our supply-demand analysis and CI trajectory analysis of conventional and low carbon fuels into California with a CI reduction trajectory from 2023 to 2040. From there, we calculated deficits and credits to determine achievable CI targets in various years. There are two key components that are not considered in this version of the Central Case: 1) a step-down mechanism and 2) an acceleration mechanism.

- The former, a step-down mechanism, is designed to reduce significantly the current over-supply of credits. At the end of 2022, CARB reported a surplus of 15 million credits. This is expected to grow significantly again in 2023. For our part, we do not consider the existing bank of 15 million credits, as we assume that these will be drawn down in some controlled fashion as part of the step-down mechanism.
- The acceleration mechanism is a concept introduced by CARB via workshop to outline an indicator or series of indicators that can be calculated and could be used to determine if the CI reduction requirements of the program need to be accelerated because of the over-performance in the market. Together, these two mechanisms should help the LCFS program find stronger footing with respect to the supply-demand balance of credits and deficits, especially in cases where innovation continues to occur more rapidly than otherwise forecast.

ICF will provide further commentary on these two policy mechanisms in other forthcoming publications.

In our modeling, ICF finds that a CI target of 41-44% for 2030 is achievable in the Central Case, as shown below, based on expected fuel volumes and carbon intensity reductions for a wide array of fuel pathways. This range excludes many crediting opportunities, including offroad electrification, infrastructure crediting, direct air capture of CO2, CCS at biogas or hydrogen facilities, and others. Further, it does not include state goals for reducing vehicle miles travelled, which would lead to significant additional average carbon intensity reductions, assuming low carbon fuel volumes remain the same, otherwise. Overall, we believe this target represents a reasonable, yet conservative, estimate of CI reduction potential under the LCFS in 2030. We present this as a range, because there is likely some desirable credit bank that the market would seek to maintain, rather than running the bank of credits and deficits to net zero. Figure 7 shows the CI reduction trajectory used as an overlay against ICF modeling to develop Figure 8 and Figure 9 below, which show the balance of credits and deficits, and the primary credit generating pathways, respectively. The results presented are for a 42.8% CI reduction target by 2030, and a linear increase in the stringency of the program thereafter to achieve a 90% CI reduction by 2045.

Figure 7. CI Reduction Trajectory Modeled for LCFS Program

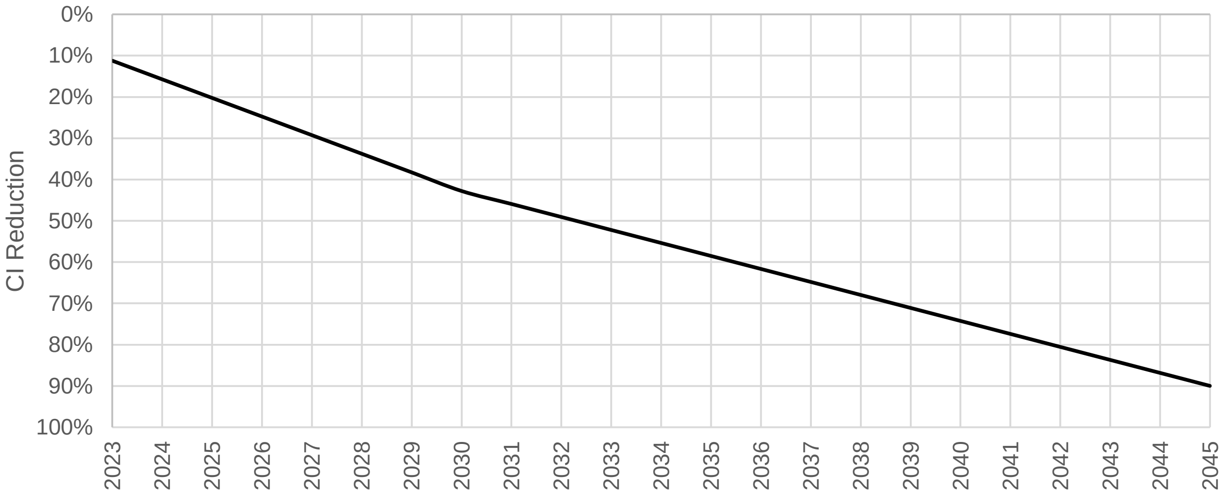


Figure 8. Balance of Credits and Deficits with a 42% CI standard in 2030, 2023-2040

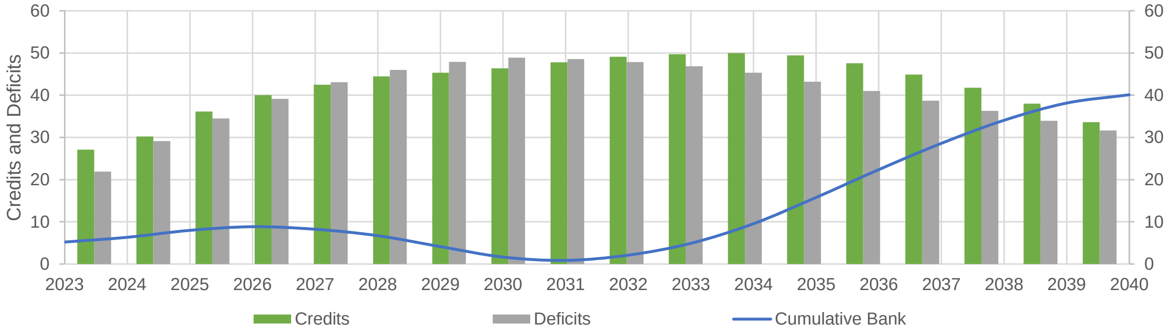
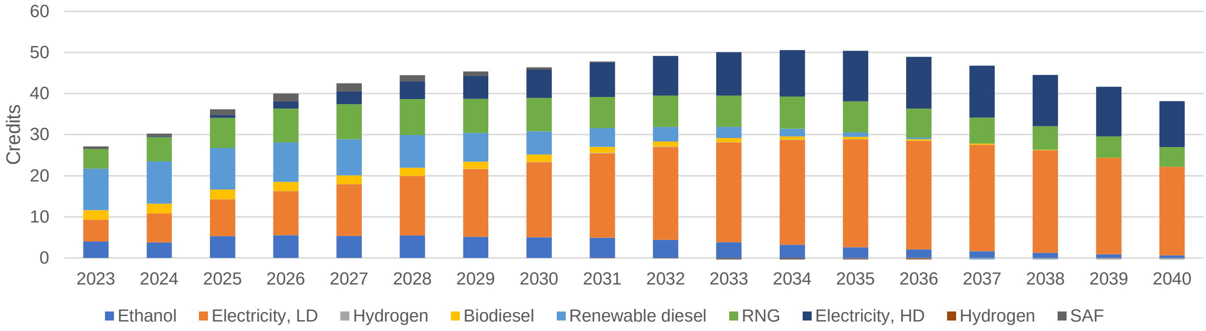


Figure 9. Primary Credit Generating Pathways in Modeling, 2023-2040



Based on this initial analysis of the Central Case, we make the following observations:

- A trajectory with a 30% CI by 2030 is borderline untenable—ICF estimates this will yield a bank in excess of 100 million credits.
- *Deficits are decreasing*. Gasoline and diesel demand are both at or near their peaks; there is only modest room for growth given California regulations. This will limit

deficit generation considerably in the next decade, especially for gasoline as transportation electrification accelerates.

- *Credit generating activity is poised to increase rapidly*. The diversity of options to achieve the range of CI target is significant. We consider higher liquid biofuels blending, lower CIs across the board, electrification of the light-duty and heavy-duty sectors, SAF deployment, expanded role of biogas, and modest hydrogen deployment. These strategies align closely with the incentive structures of the Inflation Reduction Act, and other programs (e.g., the Renewable Fuel Standard). The LCFS program will certainly help the economics of some of these projects, but many are being developed without expectations of significant price support from the LCFS program.
- *A step-down mechanism is needed sooner than later*. The bank of credits will likely be in the range of 30 million credits by the end of 2024 absent intervention—this has the potential to alter the trajectory contemplated in our Central Case. The step-down mechanism is critical for 2024 implementation—another year of banked credits will shift the program trajectory and likely limit low carbon fuel deployment.
- *Diversity of credit-generating options is strength of modeling, not limitation*. Though we have under- and over-estimated credit generation for specific strategies previously, ICF analysis has consistently shown that we are in line with LCFS market performance at the top level of credit-deficit balances.
- *Post-2030 considerations*. The CI trajectory of the program from 2030 to 2045 will need to be non-linear to prevent another build-up of credits. The full implementation of ACC2 and Advanced Clean Fleets will achieve compliance without any other low carbon fuels by 2036 with a 62% CI reduction standard.

Appendix: Accelerated Decarbonization in the High Case

As noted previously, ICF modeled the *Central Case* and a *High Case*. ICF bundled strategies to achieve into four groups (as highlighted in the table below) to quantify incremental CI reductions that could be achieved.

Table 3. Strategy Groupings Considered in ICF modeling, High Case

Strategy Grouping	Strategies for Consideration in High Case(s)
Group 1A: Market Developments	• Off-road electrification (*excluded* from Central Case) • Infrastructure crediting for hydrogen and electricity refueling
Group 1B: Market Developments w/ Investment	• Faster CI reductions across all strategies • Increased use of biogas as a process fuel • Higher NGV deployment • Increase biodiesel blending to 20% • Marginally higher ZEV adoption pre-2035
Group 2: Policy Change / Shift	• Increased FFV penetration in line with assumption that starting in 2026, all internal combustion engines (ICEs) will be FFVs
Group 3: Updated Land Use Change Science	• Modified LUC adders for the CI of fuels that are produced using soybean oil and corn ethanol to reflect current estimates in ANL GREET.
Group 4: 2022 Scoping Plan Alignment	• Carbon, Capture, and Storage (CCS) at Refineries • Direct Air Capture • *Note: excluded VMT reductions*

Summary of Strategies in the High Case

The text in the sub-sections below summarize the assumptions made for each group of changes implemented in the High Case.

Group 1: Market Developments

ICF distinguished between two types of market developments in the High Case-those that are already eligible and generating credits and those that will require additional investment and support to occur.

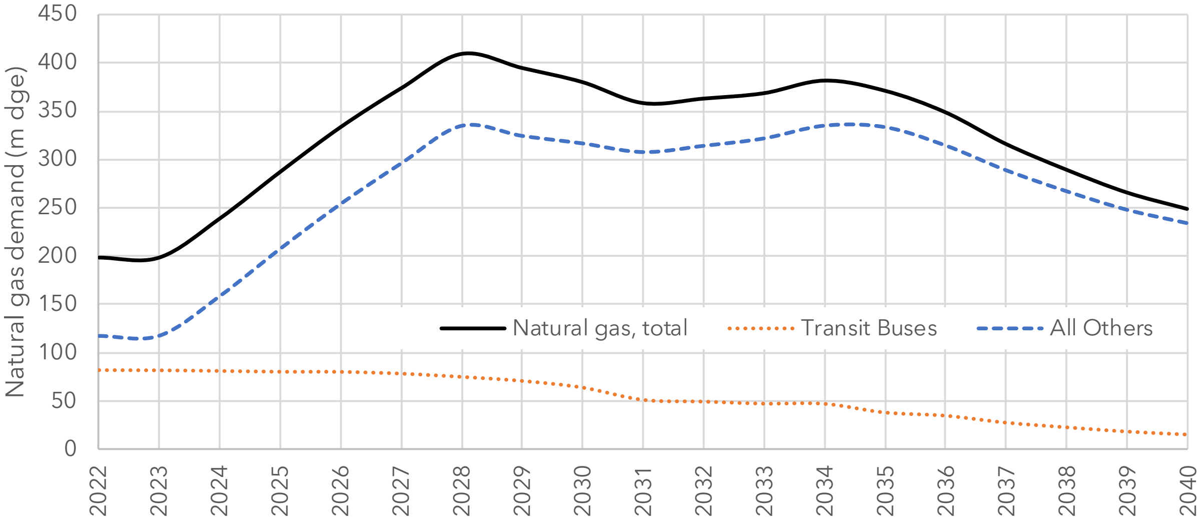
The first sub-group is focused on two areas for which LCFS credits are already generated: off-road electrification and infrastructure crediting. For the former off-road electrification, CARB has deemed several types of electricity use in different types of equipment as eligible credit generating pathways. These include electricity used in forklifts, ocean going vessels, cargo handling equipment, fixed guideways, and truck refrigeration units. In 2022, these pathways reported about 2.7 GWh of electricity and generated about 2.2 million credits in the LCFS program. For the High Case, ICF assumed that the credits generated by electric forklifts would decrease by 80% in line with potential changes proposed by CARB via workshops (e.g., requiring metering, reduced EER values, and phasing out eligibility) by 2025. ICF assumed that the other sectors would grow at a modest rate of 5% per year (for the sake of comparison, the reported electricity for offroad technologies, after excluding electric forklifts, grew by 32% between 2021 and 2022. ICF also made a similar simplifying assumption for infrastructure crediting. In 2022, about 220,000 credits were generated via infrastructure crediting, with about 130,000 credits from hydrogen refueling infrastructure (HRI) credits and about 90,000 credits from DC fast charging infrastructure (FCI) credits. The current regulation restricts infrastructure crediting to publicly accessible refueling stations and is linked to light-duty vehicle deployments for hydrogen fuel cell vehicles and electric vehicles. However, CARB has discussed adopting similar infrastructure crediting for medium- and heavy-duty fleets that are using hydrogen or electricity. It is impractical to predict the number of infrastructure credits that will be generated without a clearer understanding of eligibility and a more detailed analysis of likely infrastructure deployment to support transportation electrification (including EVs and FCEVs) in the light-, medium-, and heavy-duty sectors. For the purposes of our modeling in the High Case, ICF assumed a simple 10% year over year increase in infrastructure credits. For the sake of reference, infrastructure credits nearly doubled between 2021 and 2022, with similar growth trajectory for both HRI credits and FCI credits.

The second sub-grouping includes a variety of additional CI reduction strategies that will require additional investment support but are eligible under the existing LCFS program. These include:

- *Faster CI reductions than in the Central Case*. Generally speaking, ICF assumed modest CI decreases in the range of 1-3% in the Central Case before accounting for reductions from strategies such as climate smart agriculture, carbon capture and storage, or other ways to decrease the CI of transportation fuels through additional investment. In this High Case, we increased the CI reduction over time, on average by 1-2% each year for pathways. This is an analytical expression of additional investment to improve process efficiencies, deploy more renewable electricity, and other upstream options that will help to accelerate CI reductions in most fuels.
- *Increased use of biogas as a process fuel.* Regulatory changes to the Renewable Fuel Standard characterizing biogas as a biointermediate, IRA incentives (e.g., Section 45V incentivizes CI reductions for hydrogen, and biogas is likely to play a sizeable role in the pursuit of those reduction), and other market realities may help to improve the economics of using biogas as a process fuel. In this case, ICF deployed biogas (as RNG) in volumes consistent with those used in the 2022 Scoping Plan Update in eligible activities-most notably at refineries.

- *Higher natural gas vehicle deployment*. Despite long-term downward pressures on the use of natural gas as a transportation fuel due to regulations such as the ICT and ACF, the market has been surprisingly robust in the last several years for natural gas. There are many large- and medium-sized fleets that continue to purchase NGVs in California. As noted previously, the existing tools to understand fleet turnover in the medium- and heavy-duty sectors do not adequately consider the likelihood of NGV adoption. The reasoning behind this is simple: tools like EMFAC are used to characterize air quality impacts, and they effectively treat diesel use and natural gas use as equivalent with respect to criteria pollutant emissions under the (generally false) presumption that the engines are meeting the same standards e.g., for NOx emissions. These are not fleet turnover tools that are based on fleet purchasing patterns or total cost of ownership considerations, or other factors that might distinguish between medium- and heavy-duty vehicles that use diesel or natural gas. In the High Case, we take another simple view of natural gas use-we doubled the rate of growth in the market in the near-term and long-term, after accounting for the impacts of existing regulations. As a result of these assumptions, natural gas reaches a peak consumption of about 400 mdge in 2028 (see the figure below), and then decreases accordingly thereafter.

Figure 10. Natural gas consumption as a transportation fuel in the High Case



- *Increased biodiesel blending*. ICF limited biodiesel blending to 17%$_{vol}$ in the Central Case. This was increased to 20%$_{vol}$ in the High Case. This modest increase in volume led to no substantive changes in the mix of feedstocks used to produce biodiesel in our modeling.
- *Higher ZEV Adoption*. California continues to exceed the targets established by the Advanced Clean Cars regulation. For the first two quarters of 2023, the California New Car Dealers Association reports EVs have a 24.4% share of the market (up from 19.1% for all of 2022). In isolation, the second quarter actually showed sales

exceeding slightly the 25% threshold-and some parts of the state exceeding that significantly. Alameda, San Francisco, and Santa Clara counties have a 40% ZEV sales rate in the second quarter of 2023. ICF did not modify the ZEV shares of sales that are attributable to ACC2 (starting in 2026), however, we increased slightly in the High Case the ZEV sales rate for 2023-2025.

Group 2: Policy Change / Shift

This group focuses on the strategy to deploy E85 as a low carbon substitute for gasoline. A report published by the Institute for Transportation Studies at the University of California (UC) entitled *Driving California's Emissions to Zero*[21] highlighted the importance and challenges of reducing the CI of liquid gasoline substitutes. More specifically, UC's modeling to net zero by 2045 requires that

> to maintain the trajectory of this scenario, a low-carbon, drop-in gasoline substitute must deploy at commercial scales in the mid to late 2020s, reaching 500 million gasoline-equivalent gallons by 2030, peaking around 2.6 billion gallons in 2040, then declining slowly thereafter as the residual internal combustion engine vehicles are retired from the fleet.

The authors also note that these volumes exclude renewable naphtha volumes as a co-product to renewable diesel production. Despite the technological improvements made to increase biomass-based diesel production domestically, there has been no comparable breakthroughs for renewable gasoline at commercial scale as of today in 2023. However, after accounting for CI reductions to ethanol production due to advances in process efficiencies, climate smart agriculture, and CCS, E85 matches the description of what the UC researchers project is necessary to achieve net zero by 2045.

As noted in the Central Case, E85 volumes increased significantly in 2022 compared to 2021. However, the phase out of the FFV credit from federal fuel economy standards starting in 2017 removed the incentive for original equipment manufacturers (OEMs) to deploy FFVs, despite the low cost of doing so.[22] For the High Case, we assumed that as the result of a policy shift or change in California, that OEMs would be required to make all ICE vehicles (even those as plug-in hybrids) flex-fuel capable. The introduction of this assumption reverses the decline in E85 observed in the Central Case tied to decreased FFV population in California and

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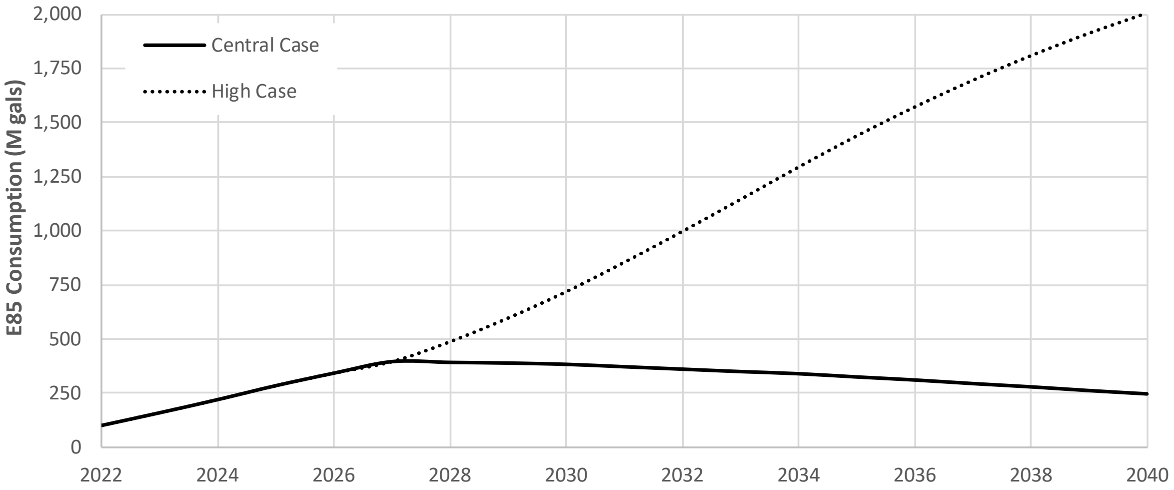
[21] Driving California's Transportation Emissions to Zero, April 2021, available online at https://escholarship.org/uc/item/3np3p2t0.

[22] Most industry sources quote a cost to the OEM of $100-200 per vehicle to make an FFV.

enables growth in E85 in line with the low carbon liquid fuel substitute that UC researchers envisioned. Despite the increased demand for E85 through the increased availability of FFVs in our revised modeling, we included an infrastructure constraint on E85 deployment, with the assumption that dispensing capacity would increase by somewhere between 100-150 million gallons per year through the modeling period.



Group 3: Updated Land Use Change Science

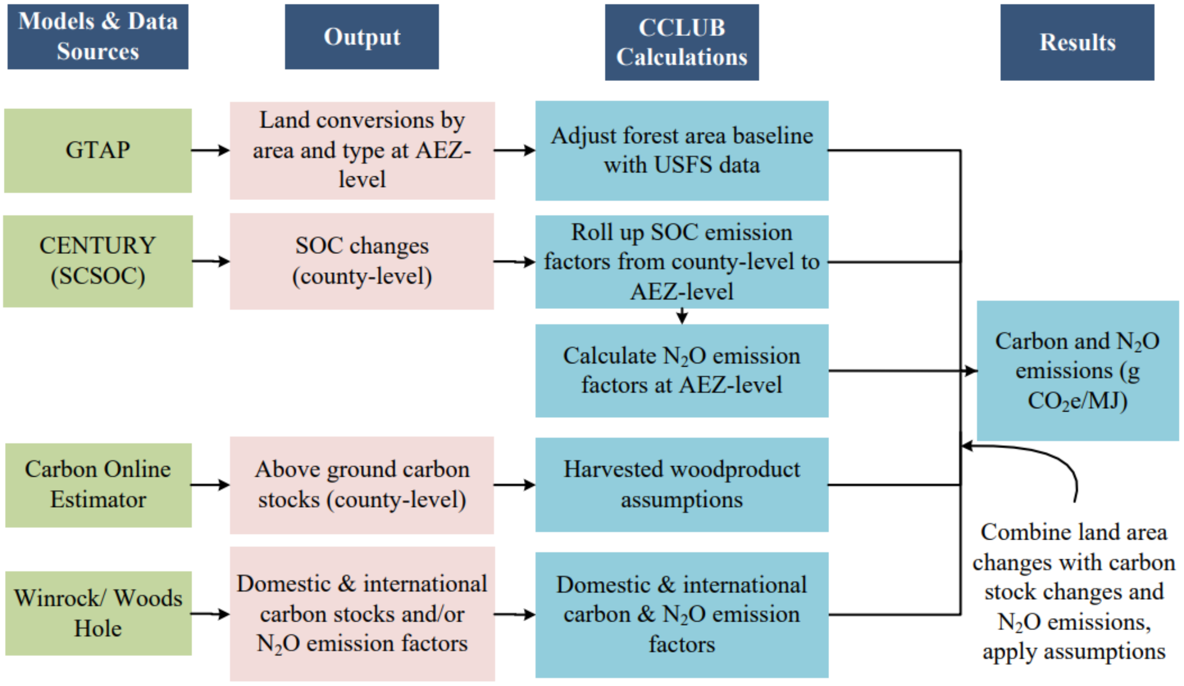
CARB last updated land use change (LUC) adders for corn (used primarily in ethanol production) and soybean oil (used in biodiesel and renewable diesel production) during the 2015 readoption of the LCFS program. That assessment assigned adders of 19.8 g/MJ and 29.1 g/MJ to transportation fuels produced using corn and soybean oil, respectively.

By way of background, LUC is defined as the shift in land-use and land-cover that *could* accompany large-scale feedstock production in cropland to produce biofuels. The LUC impact is generally calculated overt two-steps:

- Biofuel production scenarios are developed. These scenarios reflect varying shocks to the economy in response to an increase demand for a biofuel feedstock commodity.
- These biofuel production scenarios are used as inputs into a computable general equilibrium economic model or similar model to determine the associated impact.

Argonne, for instance, uses the Carbon Calculator for Land Use Change from Biofuels Production (CCLUB) as part of its GREET modeling to characterize the LUC from corn and soybean oil. The figure below provides a brief overview of the CCLUB data sources and calculations.

Figure 11. Schematic of Data Sources and Calculations in CCLUB[23]



The LUC values in the most recent version of ANL's GREET for corn (to make ethanol) and soybean oil (to make biomass-based diesel) are 7.39 g/MJ and 9.27 g/MJ, respectively. ICF used these LUC adders in the High Case.

Table 4. LUC Adders used in ICF's Modeling, Central Case and High Case

Feedstock	Central Case	High Case
Corn to Ethanol	19.8 g/MJ	7.39 g/MJ
Soybean Oil to BD or RD	29.1 g/MJ	9.27 g/MJ

Group 4: 2022 Scoping Plan Alignment

California's 2022 Scoping Plan for Achieving Carbon Neutrality (i.e., the 2022 Scoping Plan) lays out a path to achieve targets for carbon neutrality and reduce GHG emissions by 85% below 1990 levels no later than 2045, as directed by Assembly Bill 1279. CARB included substantial carbon removal strategies, including CCS and Direct Air Capture (DAC).

- *Incorporating CCS at Refineries*. ICF already considered the deployment of CCS at ethanol production facilities in the Central Case. In the High Case, ICF used the CCS assumptions from the 2022 Scoping Plan and counted these reductions toward the

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[23] Figure sourced from Carbon Calculator for Land Use Change from Biofuels Production (CCLUB), User's Manual and Technical Documentation, available online at https://greet.es.anl.gov/files/cclub-manual-r4.

credit-deficit balance of the program accordingly. For the sake of reference, CARB assumed about 12.3 MMT of reductions at refineries attributable to CCS by 2030 and decreasing to 4.9 MMT of reduction by 2040 (due to assumptions related to reduced activity at refineries in California).

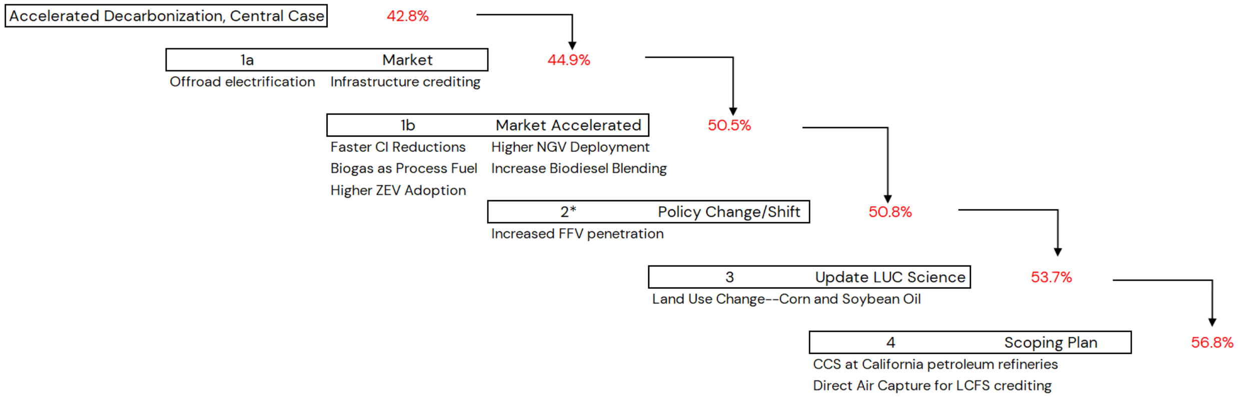
- *DAC Deployment in the LCFS program.* DAC projects can generate value in the LCFS program. The 2022 Scoping Plan relies on DAC to deliver 2.26 MMT of reductions in 2030 and 49.25 MMT in 2040.

ICF incorporated both of these potential credit generation pathways into the High Case.

Summary of Results in the High Case

The order of operations for which the groups of low carbon strategies are implemented in ICF's modeling has a material impact on the percent CI reductions attributable to each group. The results presented below focus on the CI reduction achieved in 2030, while maintaining a comparable (i.e., within 10%) cumulative bank of credits available in 2030 as in the Central Case. The figure below captures the results and the order of implementation of the strategies in ICF's modeling.

Figure 12. Summary of CI Reduction Achieved in 2030 in the High Case



Prior to implementing any of the strategies, we start from the feasible CI reduction in 2030 of 42.8%. After implementing the strategies across the four groups discussed previously, we report a CI reduction of 56.8% by 2030.

After implementing Group 1a and Group 1b, the CI reduction achieved in 2030 improves to 44.9% and 50.5%, respectively. There is only a modest benefit by 2030 after implementing Group 2, because of the timing of the change (2028) and the minor increase in ethanol consumption by 2030, and because other improvements in ethanol have already been realized. After accounting for updates to the LUC science in line with the values used by ANL, ICF reports a CI reduction of 53.7% by 2030. And lastly, after aligning more closely with the 2022 Scoping Plan as it relates to carbon removals via CCS and DAC, we report a CI reduction of 56.8% by 2030.

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