How Will Changes in the Ethanol Market Affect California's Low Carbon Fuel Standard?

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ABSTRACT

A multi-period optimization model is used to analyze how changes in the U.S. ethanol market may affect California's low carbon fuel standard (LCFS). The six market conditions analyzed include: 1) a reference scenario in which the development of the lignocellulosic ethanol industry proceeds according to the Environmental Protection Agency's current industry forecast and the ethanol tariff and federal ethanol tax credits maintain current levels, 2) a five-year delay in the development of the lignocellulosic ethanol industry, 3) accelerated growth of the lignocellulosic ethanol industry, 4) removal of the $0.54/gallon ethanol import tariff, 5) removal of the three federal ethanol tax credits, and 6) removal of both the tariff and tax credits. The most dramatic change in California's compliance pathway occurs with changes in the development of the cellulosic ethanol industry. If the industry is delayed an additional five years, Brazilian ethanol accounts for 25% of all transportation energy in the state by 2020. If the industry development accelerates faster than EPA predictions, lignocellulosic ethanol becomes the main low-carbon fuel by 2013, replacing all Brazilian ethanol. Removal of the ethanol tariff results in very little change from the reference case before 2020. Removal of the tax credits or removal of the tax credits and ethanol tariff result in no Brazilian ethanol before 2019.

INTRODUCTION

The nature of the ethanol fuels market may soon change in the United States and subsequently affect the compliance pathway of California's newly enacted low carbon fuel standard (LCFS). The LCFS seeks to reduce CO_2-equivalent (CO_2e) emissions from the state's transportation sector by 10% between 2010 and 2020 by capping the average carbon intensity of fuels sold by each fuel provider (defined as fuel producers, refiners, and blenders).

One important recent development is the failure of the lignocellulosic ethanol industry to meet previously set production goals. Lignocellulosic ethanol uses feedstock from dedicated high-yield energy crops such as switchgrass, popular trees, and willow trees as well as from waste products such as corn stover, paper mill waste, and municipal solid waste. The economic downturn in 2008-2009 coupled with falling energy prices has delayed this attractive source of low carbon transportation fuel in the near term (*1*). The EPA predicts between 6.5-25.5 million gallons of cellulosic ethanol will be produced in 2011, far short of previous forecasts (*1*). A further delay in the expansion of the industry may force fuel providers to use other low carbon ethanol, like Brazilian sugarcane ethanol, to meet the required carbon reductions in the LCFS. Some predict ethanol from Brazil to become the main alternative to corn ethanol in the U.S by 2022 (*2*).

However, the success of Brazilian ethanol imports is largely shaped by the U.S. import tariff, a policy instrument which is also subject to uncertainty. In April, 2010 Brazil's Chamber of Foreign Trade reduced Brazil's import tariff on ethanol from 20% to 0%. Subsequently, the Brazil Sugarcane Industry Association (UNICA) called for the reciprocal elimination of the U.S.'s import tariff (*3*). The 30-year old U.S. tariff was extended for one year in December 2010 but even corn ethanol trade groups like Growth Energy are calling for the tariff's elimination in 2011 (XXX).

The future of ethanol subsidies is also uncertain. The three main federal ethanol subsidies include: the blender's credit provided to firms that mix ethanol and gasoline; the small-producer tax credit for producers of traditional and lignocellulosic ethanol; and the cellulosic ethanol producer credit. There are indications that the blenders' tax credits will be reduced or eliminated in 2011 (*4*). Furthermore, following a recent report from the Congressional Budget Office that suggests tax credits on ethanol are not a cost effective means of growing the ethanol industry or reducing CO_2e emissions, there is increasing pressure from the academic, governmental, and private sectors for the elimination of all ethanol subsidies altogether (*5*,*6*,*7*).

TABLE 1 Scenario Descriptions

Scenario Name	Description
Reference	Lignocellulosic ethanol becomes available in the California fuels market in 2012 and is allowed to increase up to 5 billion gallons per year (BGY) by 2030. The U.S. import tariff and federal ethanol tax credit are maintained at current levels. Electric vehicle adoption occurs at a medium rate as defined by CARB.
No_Tariff	Reference scenario with U.S. import tariff removed.
No_Credit	Reference scenario with U.S. ethanol all federal tax credits removed.
No_Tariff, No_Credit	Reference scenario with U.S. import tariff and all federal tax credits removed.
Low_Cell_Eth	Reference scenario but the development of lignocellulosic ethanol industry is delayed five years to 2017.
High_Cell_Eth	Reference scenario but rapid expansion of lignocellulosic ethanol industry to 9 BGY by 2020.

This study uses a multi-period optimization model to investigate the compliance pathways, production costs, and CO_2e emissions under the six market conditions between 2010-2030 for fuels that are gasoline and gasoline substitutes (Table 1). The model makes production decisions from the perspective of the fuel provider and employs constraints on: 1) the expected transportation energy demand in the state, 2) the required annual average carbon intensity under the LCFS, and 3) the expected rates of change of vehicles and fuels. The main limitation of the model is the exogenous nature of the production cost parameters. However, some insight can still be gained by comparing production decisions and outcomes between scenarios. An optimization framework is a new approach to analyzing the LCFS and is attractive because it represents the most efficient allocation of money under the constraints; therefore, it may better predict the decision-making of fuel providers. The remainder of the paper applies to California's LCFS but could be adjusted to suit any LCFS.

BACKGROUND

California's LCFS

In April 2009 the California Air Resources Board (CARB) adopted the nation's first LCFS. Under this regulation, each fuel is assigned a carbon intensity based on a well-to-wheels life cycle assessment. The units are in grams of CO_2-equivalent per Megajoule (MJ) (one MJ equals 947.8 British Thermal Units (BTUs)). Fuels are separated into one of two categories: 1) gasoline and gasoline substitutes and 2) diesel fuel and diesel substitutes. Because substitution of between these two categories requires a vehicle or engine replacement, it is reasonable to analyze them independently in the short term. For simplification, this paper only addresses the gasoline and gasoline substitutes category. Since fuels vary in the number of MJs needed to travel a specified distance, CARB assigns each fuel an associated energy economy ratio (EER) that allows for comparison across fuel types. The EER values range from 1.0 for gasoline powered vehicles to 3.0 for electric powered vehicles, meaning an electric vehicle can go three times as far as a gasoline powered vehicle with one MJ of energy (*8*).

Fuel providers have the flexibility to alter fuel blends or change fuel types to meet the slowly lowering annual standard, referred to as the average fuel carbon intensity (AFCI) (Figure 1) (*9*). If a fuel provider cannot meet the standard in a given year, it can purchase emission-credits from other fuel providers that have average carbon intensities below the standard.

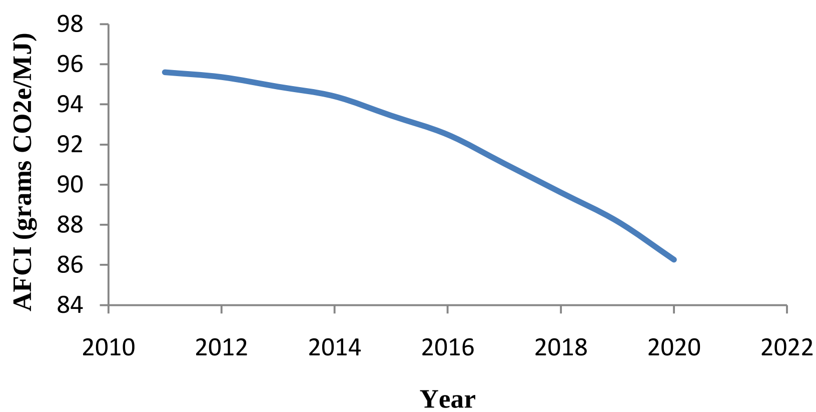

Figure 1 Required average fuel carbon intensity during LCFS standard.

The LCFS uses an opt-in system for carbon intensities. Thus, if a fuel provider can prove its production process has a lower carbon intensity than the same production process specified by the regulation, the provider can use the new value in its calculations. The LCFS will begin in 2011 following the 2010 baseline year and continue through 2020.

Lignocellulosic Ethanol Industry

California's LCFS was designed in a period in which policies and investments were aligned to induce rapid expansion of the lignocellulosic ethanol industry. The U.S. Department of Energy (DOE) awarded over $1.0 billion in grants between 2007-2008 for the research and development of advanced biofuels (*10*). By the authors' estimates, venture capitalists provided approximately $930 million more in the same time period. Most producers claimed to be 1-2 years away from full capacity production. Furthermore, the Environmental Protection Agency (EPA) established the national Renewable Fuels Standard (RFS) in 2007, requiring an increase in production of lignocellulosic ethanol from 250 million gallons per year (MGY) in 2011 to 10.5 billion gallons by 2020 (*11*). Even as late as 2009, CARB assumed that a robust advanced biofuel industry would exist by the start of the LCFS (*8*).

However, in July 2010 the EPA reported there was only one cellulosic ethanol biorefinery in production at 0.5 million MGY and that five domestic plants could come online in 2011 (*12*). The EPA expects 6.5 MGY of lignocellulosic ethanol production in 2011, far short of the RFS mandate (*12*). Because lignocellulosic ethanol has the lowest carbon intensity of any fuel in the LCFS, its availability in California could have a significant impact on the transportation fuel portfolio in the state.

U.S. Import Tariff and Domestic Subsidies

The U.S. has two types of import tariffs on ethanol: an ad valorem tariff of 2.5% and a $0.54 per gallon tariff. Additionally, under the Caribbean Basin Economic Recovery Act (CBERA) of 1989, certain Caribbean nations in the Caribbean Basin Initiative (CBI) together can provide up to 7% of the U.S.'s ethanol duty free in a Tariff Rate Quota (TRQ). This system bases one year's duty-free quantity on the previous year's total ethanol consumption. According to Yacobucci, the majority of the U.S.'s imported ethanol comes from CBI nations. Additionally, most of this ethanol originates in Brazil (*13*). Depending on the relative prices in the world ethanol market, the 7% cap may not be reached each year.

Farinelli et al. find that U.S. imported ethanol tends to be price elastic. Thus, ethanol importers readily substitute between ethanol types depending on relative prices (*14*). Although the production costs of Brazilian sugarcane ethanol are historically lower than Midwest corn ethanol, the tariff plus the added transportation cost to California mean that Brazilian ethanol has not played a large role in California's transportation energy mix. The California Energy Commission reports that in 2007, 12% of the ethanol used in California originated in Brazil (*15*).

Subsidies are another policy instrument that shapes the U.S. ethanol markets. Firms that blend ethanol with gasoline receive a $0.45 per gallon blender's credit. This credit is received regardless of the ethanol feedstock or country of origin. Additionally, lignocellulosic ethanol producers receive a $1.01 per gallon tax credit. The Energy Policy Act of 2005 also provides a tax credit to small ethanol producers (less than 60 MGY) of $0.10 per gallon for the first 15 million gallons produced. This 15 million gallon limitation does not apply to lignocellulosic ethanol. Thus, the credit may apply to all lignocellulosic ethanol up to 60 MGY.

Previous LCFS Analyses

Zhang et al. estimate how removing the import tariff affects the ethanol/gasoline blend ratio, total gasoline consumption, ethanol cost, and ethanol feedstock during the LCFS (*16*). They find that if lignocellulosic ethanol does not become commercially viable, then removing the import tariff has no effect on the amount of average blended volume of ethanol in California. In this case, 6.6 billion gallons of Brazilian ethanol are needed in 2020.

Using VISION-CI, a model developed for California's transportation sector, Farrell and Sperling build 12 scenarios - three of which exactly comply with the LCFS's mandatory 10% carbon reduction. Of these, only one illustrates a "high biofuel" scenario, requiring 2.1 billion gallons of ethanol by 2020 with an average carbon intensity of 48.7 gCO2e/MJ (*17*). This carbon intensity corresponds to roughly 50% lignocellulosic ethanol and 50% Brazilian sugarcane ethanol using average production processes.

Yeh et al. investigate if and how California can meet the LCFS (*18*). They estimate the maximum CO_2e reduction per year from various U.S.-derived biomass and electricity resources. They find that biomass from Western states could provide more than twice the reductions needed in the LCFS by 2020. Further, they find that between 5-10% of total transportation fuel demand could come from lignocellulosic ethanol sources within California by 2015. This includes biomass used for diesel and diesel substitutes (*18*).

CARB builds four compliance scenarios for gasoline and gasoline substitutes, all four of which make moderate predictions about the expansion of lignocellulosic ethanol (in 2020 there are 0.79-1.24 billion gallons of lignocellulosic ethanol in California). Again, Brazilian ethanol is given limited attention, accounting for between 0-3% of the carbon reduction by 2020 (*19*).

No analysis of the LCFS distinguishes between imported ethanol that is duty-free under CBERA and that in which the tariff is applied as done here. Further, although many LCFS analyses mention ethanol tax credits, no study specifically discusses the implications of removing the credits on California's compliance pathway. Elobied, and Tokgoz investigate the effect of removing the tariffs and tax credits on the U.S. ethanol market as a whole. They find removing the tariffs reduces U.S. ethanol price by 13.6%, whereas removing the tariffs and tax credits decreases prices by 18.4% but increases world prices by 16.5% (*20*).

METHODOLOGY

A mixed-integer optimization model is developed in the General Algebraic Modeling System (GAMS) using the CPLEX solver to find the least-cost compliance pathway for fuel providers from 2010-2030 (*21*). The model makes decisions on two variables categories: 1) the supply of each type of fuel in each year and 2) the number of lignocellulosic ethanol biorefineries built each year. A two-year time lag is included for construction of lignocellulosic ethanol biorefineries to reflect the difference between the incurred cost of construction and the start of production. With the exception of the High_Cell_Eth scenario, a maximum number of seven lignocellulosic ethanol biorefineries can be built per year. Costs incurred after 2010 are discounted at a 3% discount rate.

One simplifying assumption is that fuel providers in California are aggregated into one omnipotent provider that makes production decisions for the entire state. This assumption implies that LCFS emission credits are fully internalized by the fuel provider. Therefore, no prediction on credit pricing is needed.

Electric vehicles increase according to a logistical S-shaped adoption curve developed by CARB in their "medium electric vehicle adoption scenario" (*19*). In each year, electric vehicles can fluctuate 20% above or below the adoption curve.

The model omits a similar constraint on the flex-fuel vehicle (FFV) penetration rate. The justification is that policymakers have greater ability to adjust this rate than they do for electric vehicles. Therefore, it may be more informative to know the necessary number of FFVs to support given market conditions. Table 2 presents these FFV estimates. The calculations use FFV assumptions in CARB's Scenario One, Appendix E: between 2010-2020 gasoline will maintain a constant 10% volumetric ethanol blend and after 2015 an increasing number of FFV owners will choose E85 to fill-up their vehicles (*19*). These assumptions help simplify a complex and changing ethanol market. The EPA recently increased the allowable blend rate of ethanol in gasoline to 15% (E15) for vehicles of model year 2007 and newer and is considering E15 for older vehicles. The extent to which fuel providers will supply E15 to consumers is an open question. Other potential constraints on ethanol demand not considered here include the deployment of E85 refueling stations and the annual vehicle-miles travelled by FFV owners.

The fuel provider can produce the following seven fuel types (carbon intensities in parentheses): gasoline (95.86 gCO_2e/MJ), California ethanol (80.7 gCO_2e/MJ), Midwest ethanol (99.4 gCO_2e/MJ), electricity (40.2 gCO_2e/MJ), CBERA tariff-free Brazilian ethanol (73.4 gCO_2e/MJ), Brazilian ethanol with an import tariff (73.4 gCO_2e/MJ), and lignocellulosic ethanol. CARB has yet to assign a carbon intensity value to lignocellulosic ethanol but this analysis uses CARB's preliminary value of 20.4 gCO_2e/MJ (*9*). Hydrogen and natural gas are not used in this analysis because they constitute a small portion of vehicles in California and only limited expansion is expected over the next 10 years (*22*). Furthermore, the vehicles that are natural gas-powered largely fall under the diesel and diesel substitutes category of the LCFS. An average production process is assumed for each of the seven fuels. For example, a value of 99.4 gCO_2e/MJ is used for Midwest ethanol which corresponds to "Midwest average, 80% dry mill, 20% wet mill, dry DGS" in CARB's LCFS regulation (*9*). Lastly, all energy density calculations use the higher heating value (HHV) of fuels. The model specification and notations are listed below.

E = Fuel types (described above);
T = Time index, t = 2010,…,2030;
$DISC(t)$ = Discount rate for year t;
$P(t,e)$ = Unit cost for fuel e in year t;
C = Cost of building one lignocellulosic ethanol biorefinery;
$CI(e)$ = Carbon intensity for fuel e;
$AFCI(t)$ = Mandatory average carbon intensity;
$Dmd(t)$ = Energy demand in MJ in year t;
$Lo\_MW(t)$ = Lower bound for Midwest ethanol in year t;
$Hi\_El(t), Lo\_El(t)$ = Upper bound and lower bound for electricity in year t;
$Hi\_CAcorn(t)$ = Upper bound for California corn ethanol in year t;
Cap_cell = Capacity in MJ of one lignocellulosic ethanol biorefinery;
$I(t)$ = Number of lignocellulosic biorefineries built in year t;
$x(t,e)$ = Supply of fuel e in MJ in year t.

$$Min \qquad Z = \sum_{t=2010}^{2030} \left(DISC(t) \bullet \left(\sum_{e \in E} p(t,e) \bullet x(t,e) + I(t) \bullet C \right) \right) \qquad (1.a)$$

$$s.t. \qquad \frac{\sum_{e \in E} x(t,e) \bullet CI(e)}{\sum_{e \in E} x(t,e)} \le AFCI(t), \forall t = 2010,...,2030 \qquad (1.b)$$

$$\sum_{e \in E} x(t,e) \ge Dmd(t), \forall t = 2010,...,2030 \qquad (1.c)$$

$$x(t,"MWeth") \ge Lo\_MW(t), \forall t = 2010,...,2030 \qquad (1.d)$$

$$Up\_El(t) \ge x(t,"Elec") \ge Lo\_El(t), \forall t = 2010,...,2030 \qquad (1.e)$$

$$x(t,"CAcorneth") \le Up\_CAcorn(t), \forall t = 2010,...,2030 \qquad (1.f)$$

$$x(t,"celleth") \le \sum_{k=2010}^{t-2} I(k) \bullet Cap\_cell, \forall t = 2010,...,2030 \qquad (1.g)$$

$$x(t,e) \ge 0, I(t) = \{0,1,....,7\} \qquad (1.h)$$

(*1.a*) is the objective function which minimizes the total discounted cost. Midwest ethanol, California corn ethanol, Brazilian ethanol, and lignocellulosic ethanol costs come from supplementary data in Zhang et al. (*16*). These costs follow price trends of E85 reported by the California Energy Commission from 2010-2030 (*23*). Gasoline and electricity costs are derived from Energy Information Administration Pacific region price forecasts from 2007-2035 (*24*). These prices are translated into costs of production by subtracting a historical average profit margin for gasoline (14%) and electricity companies (10%) as reported in U.S. Census (*25*). This derivation for production costs is similar to methodology used in CARB (*19*). A limitation of this model is that all production costs are exogenously determined.

(*1.b*) is the constraint for average carbon intensity. This is based on final rule-making from CARB for all fuels except lignocellulosic ethanol as noted above (*26*).

(*1.c*) is the transportation fuel demand constraint. This constraint is based on the ten-year average annual change in transportation fuel demand within California of 2% increase per year (*27*).

(*1.d*) is the lower bound constraint for annual Midwest ethanol supply. According to the California Energy Commission, 80% of California's ethanol was from Midwest corn ethanol in 2007 (*15*). Because Midwest ethanol has relatively high carbon intensity, it disappears immediately without this constraint. Given the long history of Midwest ethanol in California's fuel mix, a maximum decrease from one year to the next of 10% change per year is allowed.

(*1.e*) is the upper and lower bound constraint for annual electricity supply. CARB provides projections for future transportation electricity supply for four electrical vehicle market penetration scenarios (*19*). Using the medium vehicle adoption scenario, an S-shaped logistical adoption curve is assumed. The supply is allowed to vary 20% above and below the S-curve.

(*1.f*) is the upper bound constraint for annual California corn ethanol supply. In recent years, many of California corn ethanol refineries have closed due to the high cost of production and operation (*28*). Given this fact, the model assumes no new California corn ethanol refineries are built in the future. This establishes an upper bound for annual California corn ethanol supply and is consistent with scenarios developed by CARB which assume California corn ethanol production of 300 MGY through 2020 (*19*).

(*1.g*) is the upper bound for lignocellulosic ethanol use in California which equals the installed capacity up to the planning year. Each lignocellulosic ethanol biorefinery has the same installed capacity of 50 million gallon per year. The capital cost for building such a refinery is $193.8 million and is based on a weighted average four types of advanced biorefineries (*16*). The EIA estimates a cost of $375 million for a 50 MGY plant but does not indicate the feedstock type (*29*). Flanders and McKissick estimate the cost of the 49 MGY biorefinery in Treutlen County, GA to be $225 million (*30*).

(*1h*) are constraints for the decision variable x(t, e) and integer variable I(t).

RESULTS

All scenarios are extended to 2030 to ensure building and production decisions are not affected by the terminus of the LCFS in 2020. Figures 2 through 7 display the annual percentage in MJs of each fuel type according to the six scenarios. The bottom 50% in each figure (not shown) is gasoline. As expected, all pathways increase the use of low carbon fuels by 2020. Because gasoline has the cheapest production cost per MJ, the model first maximizes the amount of gasoline and then uses low carbon fuels to satisfy the carbon constraint. In all cases, Midwest ethanol is replaced with a mixture of lignocellulosic ethanol, Brazilian ethanol, California corn ethanol, and electricity.

The compliance pathway is largely shaped by the substitutability of Brazilian ethanol and lignocellulosic ethanol. Not surprisingly, removing the import tariff (Figure 3) results in higher levels of Brazilian ethanol and lower levels of lignocellulosic ethanol. On the other hand, removing the tax credits (Figure 5) results in lower volumes of lignocellulosic ethanol and only a slight increase in Brazilian ethanol in 2020. When both the tax credits and import tariff are removed (Figure 4), lignocellulosic ethanol becomes relatively more expensive than Brazilian ethanol because the $1.01 per gallon producer tax credit for lignocellulosic ethanol is greater than the $0.54 per gallon import tariff. Resultantly, lignocellulosic ethanol gives way to Brazilian ethanol by 2020.

A five-year delay in the development of the lignocellulosic industry (Figure 6) creates an arguably infeasible compliance pathway. Brazilian ethanol plays a dominant role, needing 6.6 billion gallons by 2020. To achieve this, Brazilian ethanol imports would need to increase 80% per year on average through 2020 and 8.6 million FFVs would be needed by 2020. The number of FFVs needed in this case is much higher than the four LCFS scenarios developed by CARB in which 1.8-3.4 million FFVs exist in 2020 (*19*). It is also higher than estimates by the California Energy Commission (CEC) of 4.8 million FFVs in 2020 (*23*). Ultimately, the Low_Cell_Eth scenario underscores the challenges California's fuel providers could face if lignocellulosic ethanol experiences further delays.

California corn ethanol plays only a minor role in all six scenarios despite being unconstrained and having a modest carbon intensity (80.7 g/MJ). The reason this fuel does not play a more important role its high relative cost over the 20 year timeframe of the analysis.

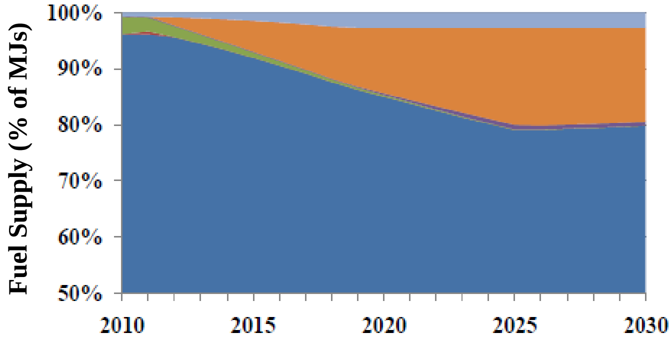

Figure 2 Reference

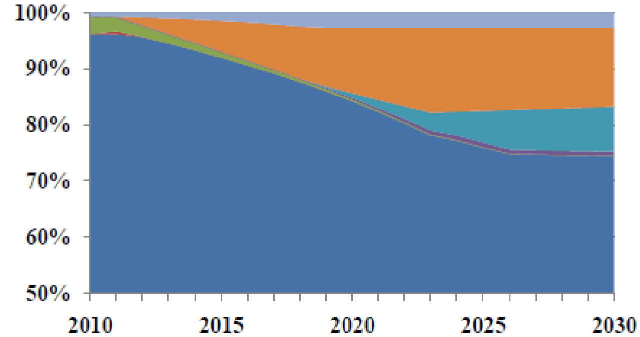

Figure 3 No_Tariff.

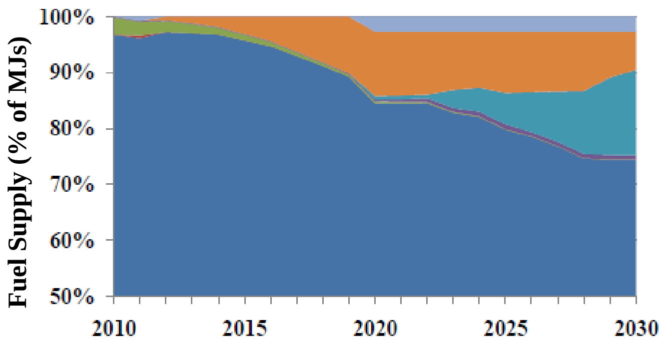

Figure 4 No_Tariff, No_Credit.

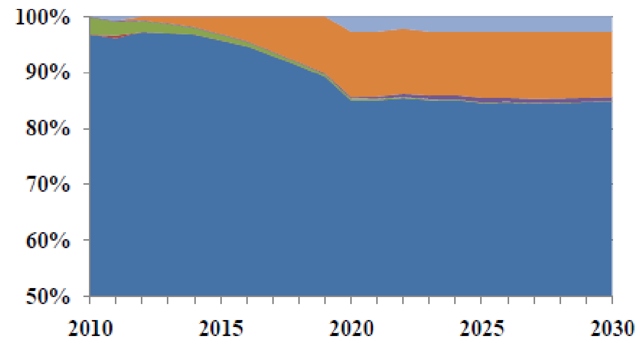

Figure 5 No_Credit.

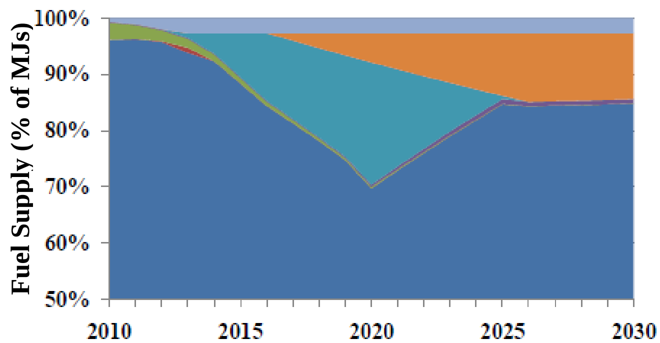

Figure 6 Low_Cell_Eth.

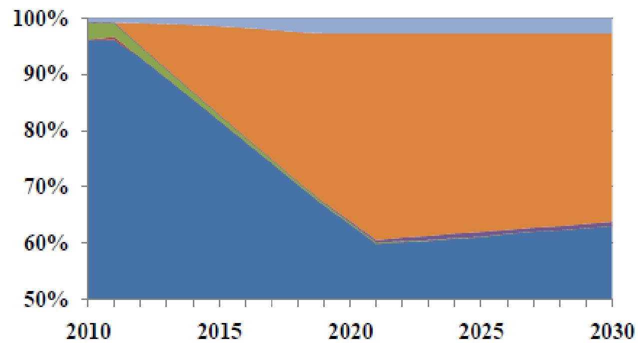

Figure 7 High_Cell_Eth.

Gas CA Corn Eth MW Corn Eth Elec Braz Eth Cell Eth Braz CBERA

*Note: Braz CBRERA is Brazilian ethanol that arrives in the U.S. duty-free under the CBERA. Braz Eth is Brazilian ethanol that includes the $0.54/gallon tariff.

Although the same average carbon intensity is reached each year across scenarios, the total costs are different (Table 2). The largest cost savings come in the High_Cell_Eth case. The extremely low carbon intensity of lignocellulosic ethanol means large amounts of low-cost gasoline can be used to meet the annual energy demand. Even though this case is highly unlikely given 1/3 of all transportation energy would come from lignocellulosic feedstock in 2020, it demonstrates the financial benefits of an extremely low-carbon fuel under a carbon performance standard.

The cumulative discounted cost to the single omnipotent fuel provider decreases only slightly from the reference case when the tariff is removed. This is because tariff removal results in only slight increases of Brazilian ethanol in lieu of higher cost lignocellulosic ethanol. The highest cost scenario is the removal of the tax credits which affect all forms of ethanol – domestic and Brazilian. While the cost to the fuel provider increases, the total societal costs may decrease due to economic efficiency gains (less deadweight loss without subsidies). However, this study does not evaluate societal costs.

TABLE 2 Costs and FFV Requirements

Scenario Name	Year	Discounted Annual Cost ($ billion)	Cumulative Discounted Cost 2010-2030 ($ billion)	Required FFV Population to Support Ethanol Supply (1,000s)
Reference	2010	32.6	713.9	63.8
	2015	37.6		141.4
	2020	35.2		4,214.5
	2030	31.0		6,189.4
No_Tariff	2010	32.6	710.6	63.8
	2015	37.7		141.4
	2020	35.3		4,451.5
	2030	29.8		11,564.7
No_Tariff & No_Credit	2010	32.9	752.0	53.2
	2015	37.9		73.6
	2020	36.7		4,370.7
	2030	33.7		9,539.1
No_Credit	2010	32.7	753.7	63.8
	2015	38.8		322.7
	2020	36.8		10,451.2
	2030	33.8		11,519.9
Low_Cell_Eth	2010	31.2	730.0	63.8
	2015	38.8		204.8
	2020	36.9		8,601.7
	2030	31.8		4,590.3
High_Cell_Eth	2010	35.1	679.1	63.8
	2015	37.9		322.7
	2020	30.2		10,451.2
	2030	28.3		11,519.9

CONCLUSION

The ethanol fuels market is important to the LCFS for two main reasons. First, U.S. consumption of ethanol is expected to dramatically increase over the next decade because of the RFS mandates, increases in flex fuel vehicles, and the increase in the gasoline-ethanol blend wall. Secondly, ethanol offers fuel providers the most flexibility of any fuel type to substitute between production processes and blend ratios. Results suggest the development of the lignocellulosic ethanol industry is a critical component to the success of the LCFS. In its absence, large volumes of Brazilian ethanol are needed to balance the high carbon content of gasoline.

The import tariff and ethanol tax credits are less important determinants of California's future fuel mix. Removing these policy instruments means the relative prices of transportation fuels shift, but since the LCFS is a performance standard, the lowest cost compliance pathway remains similar to the reference case.

This study only considers the import tariff, tax credits, and health of the lignocellulosic ethanol industry but there are a number of other uncertainties that could affect California's compliance pathway: 1) whether the AFCI will continue to decrease after 2020, 2) whether values for indirect land use change will be removed from the regulation, and 3) the market penetration rates and technology development for electric vehicles. These uncertainties represent interesting areas for future research.

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