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A comparison of contracts for difference versus traditional financing schemes to support ultralow-carbon fuel production in California

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Making substantial reductions in California's transportation greenhouse gas (GHG) emissions requires a large increase in the amount of ultralow-carbon fuels consumed within the state (defined here as fuels with a carbon intensity below 30g CO_2e/MJ). To date, existing incentives have been insufficient to spur the necessary commercialization that would allow California to produce next-generation alternative fuels in larger volumes.

This working paper expands on the analysis presented in Pavlenko et al. (2016) by conducting a cost–benefit analysis of several different financial incentives for the production of emerging technologies to produce ultralow-carbon fuels. In this paper, we compare the contracts for difference (CfD) financial support guarantee proposed in the original paper with two alternatives: (1) a flat, per-gallon subsidy similar to an approach originally proposed by the California Air Resources Board, or (2) a one-time, upfront capital grant to offset capital costs. We present a cashflow model of hypothetical costs for cellulosic ethanol projects that combines their capital costs with variable costs to estimate their needed "break-even" price for finished fuel to be viable. These projections are then compared to the market value of ethanol in California to determine how effective each policy is at bridging the gap between the market value and the production price.

Our findings indicate that a flat, per-gallon subsidy provides an insufficient signal to draw new, next-generation fuel production into the marketplace. A per-gallon subsidy that expires and is renewed annually is unlikely to provide investors with enough confidence to support new projects. Instead, the majority of the subsidy spending would go toward supporting either existing production or initiatives that were already projected to begin operating in the next few years. That leaves relatively little funding remaining in the program to support new projects. That remaining funding is far more likely to go to projects at the margins that may not necessarily need the full, per-gallon dollar value of the incentive, such as corn oil or biogas, rather than transformative, long-term investments in commercial-scale production of advanced fuels, such as cellulosic ethanol. In contrast, we find that a CfD is able to provide the most cost-effective support for new production because it leverages other incentives (e.g., Renewable Fuels Standard [RFS], Low Carbon Fuel Standard [LCFS]) to minimize its own spending, only paying out to producers when market dynamics shift or other policies drop out. The level of spending from CfD is more targeted than other policies, only paying out the exact price needed to producers to meet their agreed-upon strike price. Unlike a per-gallon subsidy, a CfD does not spend money on projects that would be viable in its absence.

Our analysis also finds that capital grants have varying effects based on the size of the projects supported. For all of the projects assessed, we find that capital grants must exceed the capital costs for a given project and offset a share of the variable costs to make the finished cellulosic ethanol competitive with the market value for ethanol. Grants for projects with a lower capital expenditures (CAPEX) value, such as bolt-on additions to first-generation projects, are generally more cost-effective, although they support smaller volumes of fuel. Larger projects require

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substantial upfront grants exceeding $100 million to drive down the price of their product.

Table 1 summarizes the cost–benefit analysis, illustrating that CfD payments are able to support equivalent volumes of new fuel production with other incentives, although at a much lower cost. In contrast, the effect of a per-gallon subsidy is diluted by payouts to existing projects, resulting in a cost that is significantly higher than the $0.60/gallon of gasoline equivalent (GGE) subsidy itself. Lastly, the capital grants have varying levels of effectiveness based on project size, with smaller facilities with lower CAPEX values being slightly more cost-effective to fund.

Table 1. Cost–Benefit Comparison

Policy	Total New Production Supported (Million GGE)	Cost ($/ GGE)	Cost of GHG Reduction ($/ton CO_2e)
Per-Gallon Subsidy	110 to 185	$2.16 to $3.64	$384 to 647
Contracts for Difference	113 to 133	$0.00 to $0.92	$0 to 148
Capital Grant (bolt-on project)	33	$0.70	$125
Capital Grant (commercial-scale project)	218	$1.54	$275

Based on our cost–benefit analysis, we draw the following three conclusions:

- **A CfD incentive structure provides the most cost-effective support.** A CfD is able to provide the most cost-effective support for new production because it leverages other sources of incentives (e.g., RFS, LCFS) to minimize its own spending, only paying out to producers when market dynamics shift or other policies drop out. The level of spending from CfD is more targeted than other policies, only paying out the exact price needed to producers to meet their agreed-upon strike price.
- **A per-gallon subsidy benefits existing producers but is not strong enough to spur new entries into the market on its own.** Although a per-gallon subsidy offers simplicity, without a long-term guarantee, investors are unlikely to treat its value as close to face value. That translates to most of the support going toward existing producers, doing little to stimulate new production. This dilutes the effectiveness of a per-gallon subsidy at encouraging new entries into the market, particularly those that may be several years from beginning production.
- **Capital grants may not be enough to make advanced alternative fuels competitive**. Capital grants alone are unlikely to reduce the costs of advanced alternative fuels down to the level of the market value of ethanol, because feedstock costs and other variable costs still represent a substantial fraction of the overall price of production. For smaller projects with lower feedstock costs, such as bolt-on additions to first-generation projects, capital grants may be more effective.

Introduction

California has set an ambitious goal of reducing its statewide greenhouse gas (GHG) emissions to 40% below its 1990 emissions levels by 2030 through a combination of rules and policies. GHG mitigation in the transportation sector will largely come from a mix of vehicle electrification, improved efficiency, and a transition to lower-carbon fuels. Existing policies for low carbon fuels, such as the Renewable Fuels Standard (RFS), have helped to scale up the production of first-generation biofuels, but overall the fuels industry has fallen short of bringing the next generation of ultralow-carbon fuels (here defined as those produced from emerging technologies with a well-to-wheel carbon intensity below 30 gCO_2e per MJ) into full commercial production. This shortfall belies the necessity of additional policy support to help bridge the gap and make commercial production of the lowest-carbon fuels a reality in California.

In support of this objective, the International Council on Clean Transportation recently published a policy paper that developed a proposal for a new financing mechanism for supporting the production of ultralow-carbon fuels in California through contracts for difference (CfDs; Pavlenko et al., 2016). The proposed policy uses a two-phased approach to identify and support ultralow-carbon fuel producers in California: (1) the state holds a reverse auction to establish a price floor for a set volume of ultralow-carbon fuel to be produced over 10 years, wherein participants progressively bid lower strike prices (i.e., price floors) for their finished products; (2) the winner of the auction enters a 10-year contract that “locks in” the strike price set by auction for that producer, with the state paying the difference between the market value of the fuel and the strike price for the full 10 years. The funding for the CfD program would be taken from California’s greenhouse gas reduction fund (GGRF), which is generated through the proceeds of California’s Cap and Trade program.

Pavlenko et al. (2016) argued that CfDs provide a durable support mechanism for fuel production that would mitigate market and policy uncertainty more effectively than per-gallon subsidies. The paper contended that a CfD approach provides the necessary investment assurance to facilitate the alternative fuel industry's growth from incremental improvements in existing technologies to more risky transitional and leapfrogging technologies that offer greater carbon reductions (Fulton et al., 2014). This supplement to the original report is intended to assess the relative cost-effectiveness of the proposed CfD policy to alternative incentive schemes through a cost–benefit analysis. The alternative funding mechanisms explored in this analysis include two more traditional methods of supporting alternative fuel production: (1) fixed, per-gallon production subsidies; and (2) one-time, grant-based funding. To compare the incentive types, this report uses potential funding levels derived from discussion documents released by the California Air Resources Board (CARB) for the Air Quality Improvement Program (AQIP) Funding Plan and then assesses the amount of ultralow-carbon fuel production that could be supported by each incentive type at that funding level. The amount of fuel production supported through each incentive is estimated based on two factors: (1) the baseline costs of producing cellulosic ethanol estimated through a cashflow model, and (2) the impact of each incentive on cellulosic ethanol's *perceived* market value to investors.

Methodology

This analysis compares three different methods of supporting ultralow-carbon fuel production in California to determine which method can most cost-effectively stimulate production of additional volumes of fuel. This section first provides an overview of the cashflow model used to estimate the production and financing costs for cellulosic ethanol to estimate the strike prices that would be needed to support financially viable production for a variety of hypothetical California cellulosic ethanol producers. These strike prices factor in the money needed to break even on a given project as well as to generate a profit. Second, this section summarizes the methods used to quantify the price and benefit for each of the three incentive structures assessed in the report.

Our assessment is informed by basic cellulosic ethanol production cost estimates derived from the cashflow model. Each facility's costs are derived from a literature review of upfront capital expenditures for different production facilities and variable costs tailored to California-specific cellulosic ethanol production. Using the estimated "break-even" prices for each facility, we then determine the extent to which each of the three policies can support new ultralow-carbon fuel projects in California.

Each of the three incentive approaches evaluated in this report is an attempt to bridge the gap between the existing market value of alternative fuels and the price needed to make their production viable, in order to provide greater certainty to alternative fuel investors. The methodology to calculate the effectiveness of each individual approach differs because they target differing components of the gap between petroleum and alternative fuels, such as ongoing production costs, initial capital expenditures, or market and political uncertainty.

The three incentive strategies assessed are:

- **Per-Gallon Production Subsidy:** A per-gallon production subsidy is a common incentive type supporting the production of certain types of alternative fuels that pays a set price for every unit of qualifying fuel produced.
- **Contract-for-Difference:** A CfD approach, explained in more detail in Pavlenko et al. (2016), implements a strike price (i.e., price floor) guaranteed via contract for a set period of time, during which California would pay the difference between the market value of a finished fuel and the agreed-upon strike price. The strike price would be determined for a given project through a competitive reverse auction, wherein interested producers of ultralow-carbon fuels bid to secure the lowest strike price they would be willing to support.
- **Capital Grants:** Grants reduce the initial capital expenditures (CAPEX) of qualifying projects, thus reducing the upfront cost as well as the ongoing expenses associated with loan servicing.

We assume that each incentive is funded by $40 million of annual funding from California's GGRF. This paper assesses all three incentive structures by determining the extent to which they would stimulate additional production of ultralow-carbon fuel relative to a baseline alternative without GGRF funding. The impact on new ultralow-carbon fuel production is quantified in terms of the gallons of gasoline equivalent (GGE) of ultralow-carbon fuel produced that would not have been produced without the financial support. This impact is then normalized in units of each dollar spent by the state of California per GGE of new production.

PER-GALLON PRODUCTION SUBSIDY

A per-gallon production subsidy is an incentive that pays a flat fee per unit of qualifying ultralow-carbon fuel produced. The cost–benefit analysis presented here is based on the incentive structure presented in the April 2016 discussion document released by CARB in the April 2016 funding proposal for the Air Quality Improvement Program (CARB, 2016b). As currently drafted, this subsidy would benefit existing production as well as new projects, although eligibility for existing projects may be revised in later iterations. Our analysis conservatively assumes that after accounting for funding directed toward existing production, any remaining funding from a per-gallon incentive would then go toward supporting new production. In practice, this may not be the case. Existing projects are far more likely to get funded because they have a much lower barrier to participation compared with projects that have not yet been financed and built.

Pavlenko et al. (2016) argued that, without a long-term policy commitment, financial incentives for alternative fuel production may be heavily discounted by potential investors in new production projects, even if the values of those incentives have a high nominal value. CARB's original proposed policy has no long-term funding or security and is thus likely to have a low perceived value to investors and new projects in implementation. Because of this uncertainty and the fact that existing projects would be able to qualify for this subsidy, the proposed incentive would likely support existing production rather than provide a sufficient policy signal to generate new production.

In our analysis, we first estimate the amount of existing fuel capacity that would qualify under the definition of ultralow-carbon fuel in the proposed subsidy in California to determine how much the program would support existing production. We then assume that this production will grow linearly based on projections derived from Environmental Entrepreneurs (E2; 2014). We assume that the baseline production that is projected to occur in the absence of an additional, per-gallon subsidy will have the first access to any additional funding. Once the cost of supporting existing production is established, we assume that the remaining funding could go toward new projects.

Our assumptions of the per-gallon incentive's ability to stimulate new production differs from the cost analysis prepared by CARB and released in its Proposed Fiscal Year 2016-17 Funding Plan for Low Carbon Transportation and Fuels Investments and the Air Quality Improvement Program approved in June 2016 (CARB, 2016a). CARB's analysis suggests that the subsidy would go entirely to supporting new projects, despite the lack of a long-term funding mandate for the program. In CARB's analysis, the authors assume a middle-range cost that takes into account the average incentive amount for in-state feedstock production and an additional benefit for aiding disadvantaged communities, arriving at a cost of $0.60/GGE. The authors assume that an even split of gasoline and diesel replacements (at 40% of the carbon intensity of the fossil fuel baseline) would qualify for the subsidy, using the entire program budget in the first year. With that methodology, the program cost is a relatively straightforward $0.60/GGE of fuel.

First, we assess the baseline and projected ultralow-carbon fuel production in California that would qualify for the original incentive proposed by CARB. Our analysis uses the existing biodiesel, cellulosic ethanol, and biogas-to-liquid production in California from residue and waste feedstocks as a proxy for qualifying ultralow-carbon production in the state. We use a linear projection from E2 (2014) to determine the projected growth from the baseline for the next 10 years to determine how much fuel may have been produced in the absence of the per-gallon subsidy that could qualify for the subsidy. Although the degree to which a per-gallon subsidy would actually drive new production is questionable, this analysis assumes that any funding left over after paying out to baseline producers would support new production at the same, middle-range $0.60/GGE rate that CARB used in its original analysis.

Table 2 shows that at the time of writing, ultralow-carbon fuel production in California equals approximately 25.2 million GGE, hypothetically securing roughly $16.6 million of the $40 million allocation to the Very Low Carbon Fuels Incentive Program. The remaining $23.4 million of funding would thus be available for funding additional projects.

Table 2. Existing Ultralow-Carbon Fuel Capacity in California

Feedstock	End Product	Capacity (GGE)
Beverage Waste	Ethanol	2.7
Misc. Residues	Ethanol	0.1
Used Cooking Oil	Biodiesel	22.1
Food Waste	Biogas	0.2
Total		**25.2**

Source: Developed from facility location data from Ethanol Producer Magazine (2016) and Biodiesel Magazine (2016)

Therefore, to estimate the cost-benefit for this policy, we estimate the leftover funding for each year from 2017 through 2026 and subtract the funding that would be paid out to baseline + projected producers. From there, we assume that the remaining funding would support new production at the $0.60/GGE rate proposed by CARB. Our linear estimate of baseline projected production capacity suggests that by 2026, there would be from 67 to 94 million GGE of production in California, thus crowding out the available funding toward the end of the 10-year period assessed. Based on the level of baseline production growth assumed, remaining funding to support new production beyond the baseline could reach zero as soon as 2023 (see Figure 1). The total amount of ultralow-carbon fuel production supported over 10 years ranges from 110 to 185 million GGE through this policy, after accounting for funding going to support baseline plus baseline-projected production.

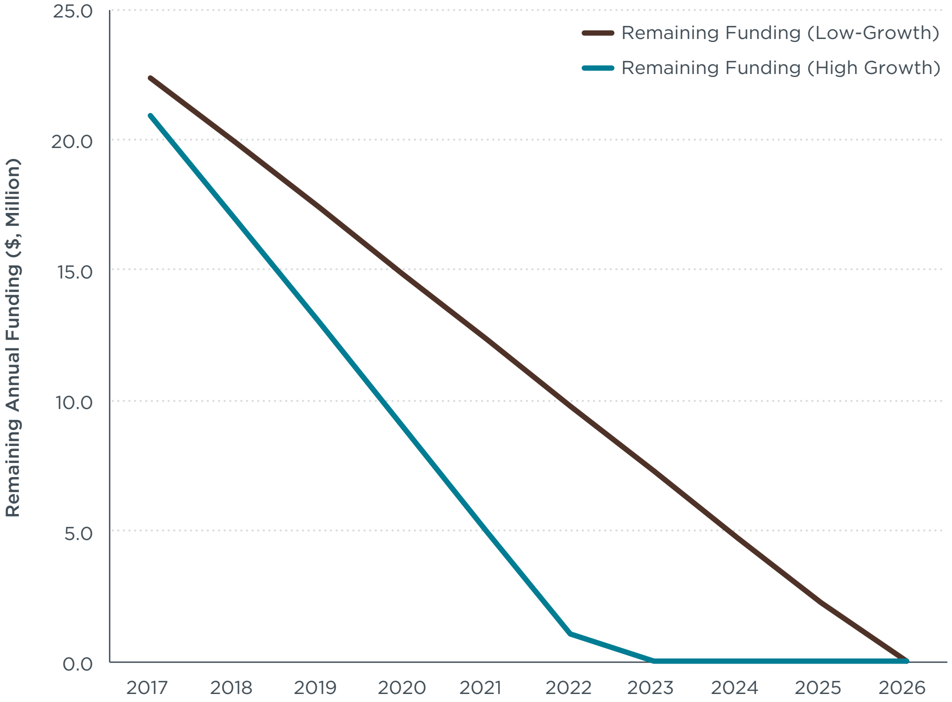

Figure 1. Remaining Annual Per-Gallon Subsidy Funding After Supporting Baseline Plus Projected Baseline Production

$$\textit{Debt-Service Coverage Ratio} = \frac{(\textit{Net Income})}{(\textit{Total Debt Service})}$$

Equation 1. Debt–Service Coverage Ratio

CASHFLOW MODEL

This study develops a cashflow model to construct a partial cost curve for cellulosic ethanol production in California. The cost curve represents a set of 12 theoretical cellulosic ethanol projects informed by a literature review of CAPEX prices and the fuel price (in $ per GGE of cellulosic ethanol) necessary for that project to pay off its fixed and variable expenses as well as generate a reasonable return on its initial investment. The price generated from the cashflow model is called the “strike price” for the purposes of this report and is used to determine the impact of CfD and grant funding on the costs of ultralow-carbon fuel production relative to those fuels’ market values. The cashflow model has a slightly different set of assumptions for a small, bolt-on project (i.e., a capacity under 10 million GGE) and larger, commercial-scale facilities.

The cashflow model aggregates the net present value of all costs attributable to biofuel production for a variety of example facilities collected through a literature review, as well as any non-biofuel income (e.g., electricity sales). The model assumes that for a given facility to be a successful investment, it must generate sufficient cashflow to not only pay off interest, principal, and operating expenses, but also to generate profit. This ratio of net income to debt service, the debt-service coverage ratio (DSCR), generally must exceed 1 for a project to pay off its expenses; a higher value also makes it easier for that project to obtain a loan. The cashflow model assumes a DSCR of 1.2, a lower-range estimate that factors in the stabilized income from the CfD policy. As the perceived risk of a given project increases, a DSCR would need to be higher to reassure investors. The internal rate of return (IRR), which reflects the profit for a given project as a share of its initial investment, ranged from 10% to 15% for the projects in the model.

The net income from each theoretical cellulosic ethanol facility is calculated from the following components:

- **Capital Expenditures (CAPEX):** CAPEX refers to the sum of capital expenditures for the project—generally the physical components of the project, such as land, equipment, and construction. CAPEX is assumed to equal the value of the principal for the project for the purposes of determining debt and interest.

- **Interest:** This refers to the interest paid to service the initial debt taken on to pay the CAPEX. This value is calculated on the basis of an 80:20 ratio of money borrowed (debt) vs. equity raised from selling interest in the company. The weighted average cost of capital (WACC), a weighted average of the interest payments for these two sources of financing, is used to determine the annual interest payments.
- **Feedstock Cost**: This refers to the ongoing costs of acquiring feedstock to convert into biofuels. Feedstock costs collected for the model include corn stover, woody biomass, rice straw, and wheat straw.
- **Chemical Cost**: This value incorporates the ongoing costs of purchasing chemicals for enzymatic transformation of cellulosic feedstocks into liquid fuels. These chemicals include enzymes, acid, and yeast.
- **Fixed Operating Costs**: On top of one-time expenses and ongoing variable costs that scale in proportion to the amount of feedstock converted, each facility has fixed operating costs to pay for employee salaries, maintenance, and other overhead.
- **Electricity Sales**: The cashflow model assumes that each facility is able to combust byproducts to generate excess electricity beyond that needed to power a facility. The excess is sold back to the local electricity grid.

$$DSCR\ (1.2) = \frac{(\textbf{Total Fuel Sales} + \text{Total Electricity Sales} - \text{Total Feedstock Costs} - \text{Total Chemical Costs} - \text{Total Fixed Operating Costs})}{(\text{CAPEX} + \text{Total Lifetime Interests})}$$

Equation 2. Calculation to Determine Fuel Price

Taking into account the previous variables, the calculation to determine the total fuel sales for a given project's fuel is shown in Equation 2. Using the rest of the known variables above as model inputs, the cashflow model solves for the present value of the total lifetime fuel sales for each project. From there, the strike price is calculated by dividing the net present value of the project's total fuel sales throughout a project's 15-year lifetime by the total volume of fuel production during that time.

The cashflow model assumes that a project will be in operation for 15 years, although a portion of the first few years will be at partial capacity during the start-up period. The start-up period is assumed to be a transitional period where the facility goes from zero production toward its full capacity, as has been demonstrated for existing cellulosic fuel facilities. After construction is complete, this study assumes that a commercial-scale project will have a start-up time of 5 years, whereas a bolt-on facility is assumed to have a start-up time of only 2 years as a result of its smaller size and reduced complexity.[1]

The CAPEX values and production capacities for the 10 commercial-scale projects included in the cashflow model were adapted from Peters et al. (2015), whereas the data for the two, smaller bolt-on facilities included in the analysis were developed from a literature review. The project specifications from Peters et al. (2015) were derived from a series of interviews and studies of existing and planned cellulosic ethanol facilities worldwide. To adapt the data to the California market, the cashflow model derives its feedstock costs and electricity sales prices from California-specific data. The fixed costs and chemical costs are derived from Peters et al. (2015) and U.S. national-level data because of a lack of California-specific examples. For an overview of the inputs into the model, see Table 3. A more detailed description of the financial variables and methodological assumptions of the model is available in Appendix A.

Table 3. Summary of High-Level Inputs in the Cashflow Model

Input	Value
Capital Expenditures (CAPEX)	$8.5-$550 million
Debt Service Coverage Ratio (DSCR)	1.2
Construction Time	2 Years (Bolt-On) 3 Years (Commercial-Scale)
Start-Up Time	2 Years (Bolt-On) 5 Years (Commercial-Scale)
Facility Lifetime	15 Years

Source: Assumptions derived from Peters et al. (2015)

The cashflow model generates an estimate of the necessary per-GGE price to secure a favorable return on investment for each of the 12 projects modeled. The model output consists of a per-GGE price for each facility from lowest to highest, similar to a supply curve (see Figure 2). However, unlike a traditional supply curve that

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[1] This analysis uses a conservative assumption wherein each project ramps up production from the end of construction through to reaching full capacity. This assumption of 50% production capacity was informed by observed start-up phases for commercial-scale projects in the United States that did not reach full production immediately (Jessen & Schill, 2016; POET-DSM, 2016).

projects the total volume of product supplied for each price, the x-axis refers to the number of facilities that are viable at that price, rather than the number of GGEs produced. The strike price supply curve is presented in contrast to the price of cellulosic ethanol after factoring in all available incentives, approximately $2.23 per GGE. Drawing upon Miller et al. (2013), the Second-Generation Biofuel Producer Tax Credit (SGBPTC) is discounted from $1.01 per gallon to $0 to account for its short duration and high uncertainty, whereas credits from the RFS program and LCFS are discounted by 50% of their 2016 values to account for policy uncertainty.

The outputs from the cashflow model indicate that the viable prices for the projects in the model range from approximately $4.50 to $9.00 per GGE of cellulosic ethanol. Several of the projects in the analysis had an estimated price of $5.00 per GGE, which indicated a favorable price relative to the market value of ethanol plus the nominal value of incentives (e.g., LCFS credit values, Renewable Identification Numbers [RINs]; Pavlenko et al., 2016). This indicates that as long as the policies are in place at similar values, the CfD payouts would be minimal.

The strike price outputs from the cashflow model feed into the CfD and grant-based funding methodologies of this report. The CfD cost-benefit analysis uses the strike price data from the cashflow model to determine example production capacities and strike prices, and from there determines how much fuel production the CfD policy supports and at what price. The grant-based funding analysis uses the cashflow model to determine the extent to which an upfront grant drives down the strike price by offsetting capital costs.

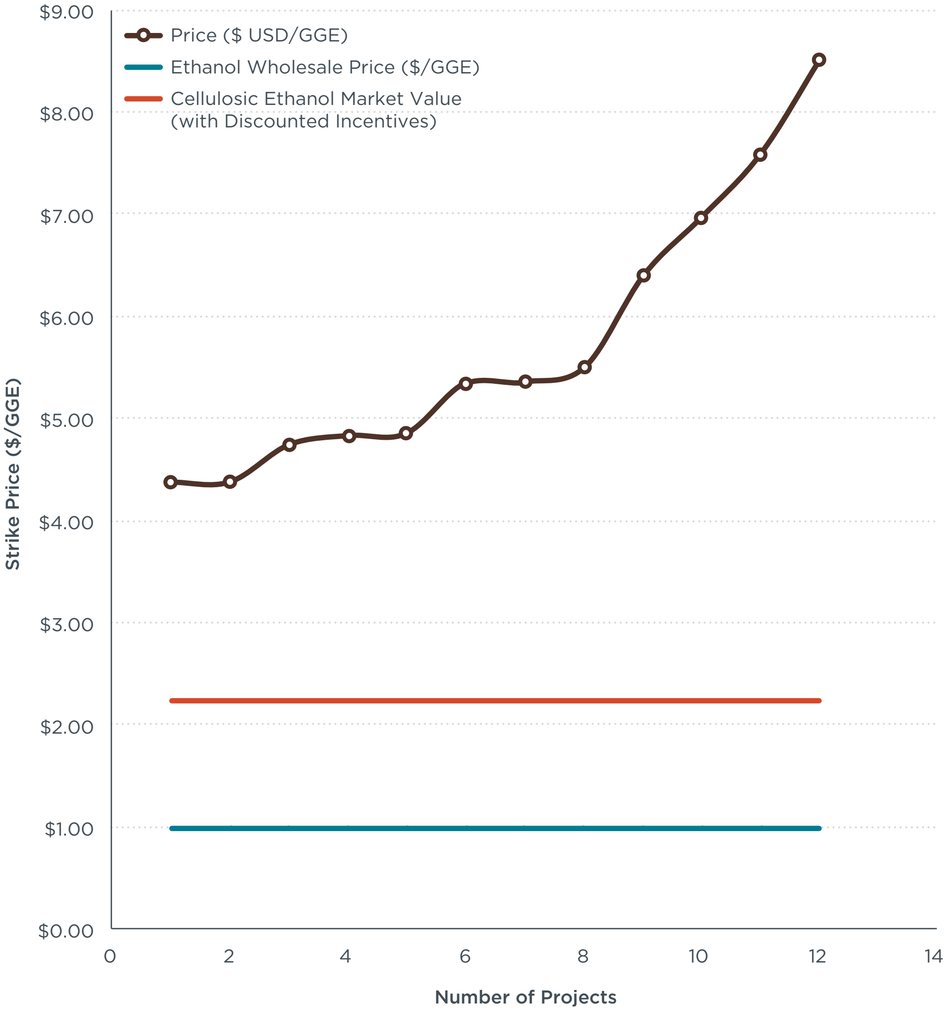

Figure 2. Project Strike Price in Cashflow Model vs. Cellulosic Ethanol Market Value

The cost–benefit analysis is derived from the cost modeling done in Pavlenko et al. (2016); the facility size and strike prices derived from the cashflow model are used to estimate how much fuel production would be supported in a given year and at what cost. In the original study, the strike prices are based on the nominal values of existing incentives (the theoretical Maximum Administrative Strike Price), and the auction volumes are based on available program funding, rather than the size of a given project (such that multiple qualifying projects could contribute to the total volume).

CONTRACT FOR DIFFERENCE SUPPORT

The cost–benefit analysis for the CfD policy uses the example project strike prices derived from the cashflow model to determine the level of support needed for those projects across a variety of different policy scenarios. This analysis assumes that all 12 of the projects modeled in the cashflow analysis would be available for the California market and would be offered up in a reverse auction. The strike prices and production capacities from the example projects are input into the cost model developed in Pavlenko et al. (2016) so that each individual program auction for the CfD would go to support an individual project, with support transitioning from small projects at the outset to larger projects in later auctions. For example, the small bolt-on facility with a break-even price of $4.43/GGE would win the first auction (rounded to the nearest $0.25) with a bid of $4.50/GGE. From there, we model the market value of the finished fuel under three policy scenarios to determine the fuel's value relative to the strike price.

Depending on a variety of policy and market factors, the market value of finished ultralow-carbon fuel could meet, fall below, or even exceed the strike price established through the reverse auction. For example, in an optimistic scenario, the sum of the LCFS credit value, RIN, and Second-Generation Biofuel Producer Tax Credit (SGBPTC) would exceed the strike price and generate a surplus of value. In contrast, in a pessimistic policy mix, a decline in policy support would necessitate payouts from the CfD program to maintain the strike price for the producers. This effect is illustrated in Figure 3. For this analysis, we conservatively assumed that a market value above the strike price did not feed back into the program, thus preserving the upside for producers.

Building on the cost modeling demonstrated in Pavlenko et al. (2016), this analysis assumes that the CfD policy would have $40 million of annual, non-guaranteed funding through 2030 and that auctions would be triggered every 2 years as long as there was sufficient funding to guarantee the liability for additional projects. The policy scenarios included estimate the existence and value of different alternative fuels policies through 2030, as follows:

- **Baseline Policy Mix Scenario:** RFS and LCFS continue through 2030, SGBPTC ends after 2017. Fossil fuel prices stay steady.
- **Optimistic Policy Mix Scenario:** RFS and LCFS continue through 2030, SGBPTC continues through 2030. High fossil fuel prices.
- **Pessimistic Policy Mix Scenario:** LCFS continues through 2030. RFS ends after 2022, SGBPTC ends after 2017. Low fossil fuel prices.

Using the strike prices developed in the cashflow model, the CfD cost–benefit analysis assumes that, over time, the program travels "up" the cost curve, as shown in Table 4. Figure 3 indicates that there are a variety of potential projects available at under $5.00/GGE. Therefore, the first auction modeled supports the smallest, cheapest bolt-on facility with a strike price of approximately $4.50/GGE, whereas a follow-up auction yields a slightly larger bolt-on facility with a capacity of 7 million GGE for $5.00/GGE. The subsequent auctions yield projects at around 20 million GGE for $5.00/GGE. Our analysis assumes that only the most efficient projects win auctions. Therefore, from the fourth auction onward, the project that has a capacity of 20 million gallons per year (MGY) at under $5.00/GGE wins. None of the

Table 4. Project Strike Price and Production Capacity for Each CfD Auction

Auction Number	Strike Price ($/GGE)	Production Capacity (Million GGE)
1 (2018)	$4.50	1.4
2 (2020)	$5.00	7
3 (2022)	$5.00	19
4 (2024)	$5.00	20
5 (2026)	$5.00	20
6 (2028)	$5.00	20

Note: Each estimated strike price is rounded to the nearest $0.25.

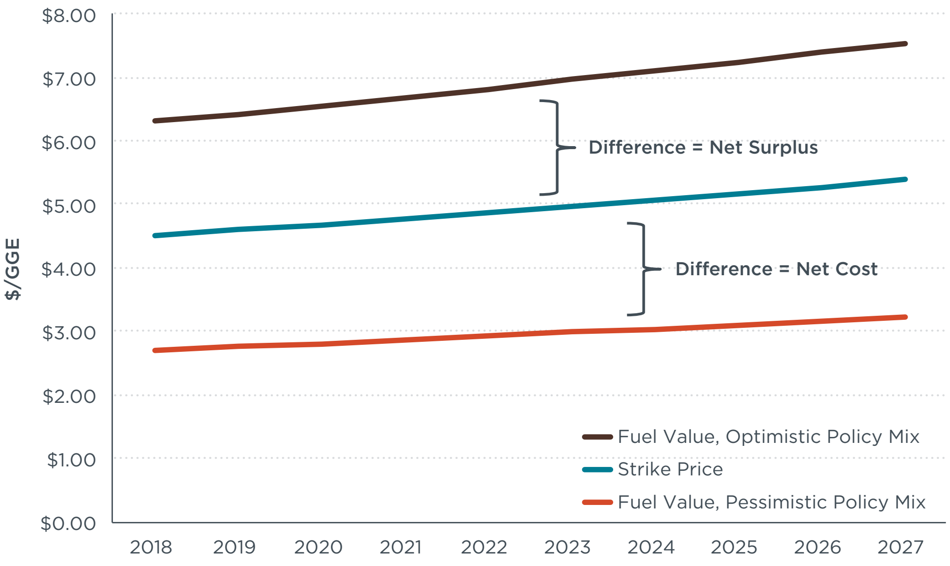

Figure 3. Impact of Policy Mix on CfD Program Cost

projects priced above $5.00/GGE are considered viable for a CfD program. Therefore, the strike price and capacity cap out at $5.00/GGE and 20 million GGE, respectively. It is likely that as technology improves and commercial-scale operators accrue experience, facilities' strike prices and capacity could improve toward 2030.

To estimate the cost-effectiveness of this incentive structure, we modeled the growth in CfD-financed fuel production from 2018 through 2030, increasing the supported volumes as each auction resolved (adjusting for construction and start-up time). After determining the volume of supported fuel production in each year, we subtracted the strike price from the market price for each project on an annual basis to determine the total spending. In the optimistic policy mix scenarios, this resulted in a net surplus that paid money into the program, whereas in the pessimistic policy mix, the CfD program paid out funding in many years. The CfD costs were then normalized for each policy mix by dividing the total sum paid out by the total volume of fuel production supported.

Capital Grant Support

The cost–benefit analysis for capital grant project support used the cashflow model to determine the impact of an upfront grant on the costs for a variety of projects in the model. As demonstrated from the cashflow model, CAPEX and ongoing debt service constitute a large share of the final per-GGE price for finished fuels from a given project, generally 30%–40% of the model's calculated strike price. To estimate the impact of a grant on a given project, this analysis uses the cashflow model to calculate the funding necessary for a given project to produce fuel at a price equal to the market value of ethanol. Pavlenko et al. (2016) emphasized that long-term investments in ultralow-carbon fuel production are constrained by investor discounting of financial incentives; thus, only the projects whose final price approaches that of the market ethanol value are considered "viable."

This analysis first considers three levels of grant funding: a "low" level of $500,000, a "medium" level of $10 million, and "high" value of $40 million. The low level of funding was informed by the U.S. Department of Agriculture's (USDA) Rural Energy Assistance Program (REAP), which is designed to aid agricultural producers and rural small businesses with the financing of new renewable energy systems. The value of the grant cannot exceed $500,000 or 25% of the eligible project costs, whichever is lower (USDA, 2015). Similarly, the USDA's Biorefinery Assistance Program is limited to supporting only 30% of a project's capital costs.

The projects assessed for this analysis include the same set of projects assessed in the CfD cost–benefit analysis that fall under the $5.00/GGE threshold. The CAPEX values for these projects range from $8.5 million for a small, bolt-on project with limited production to over $200 million for a larger, commercial-scale project.

The effectiveness of the grant-based mechanism is assessed based on

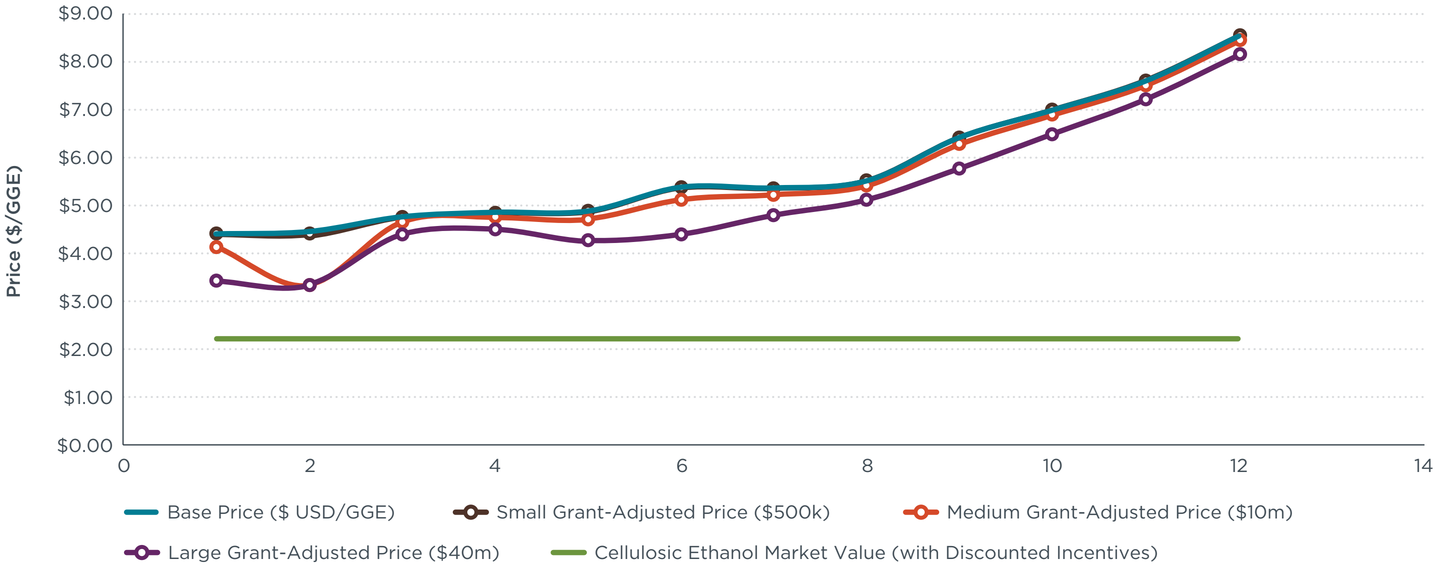

Figure 4. Baseline and Grant-Adjusted Strike Prices in the Cashflow Model

how it brings down the prices from the cashflow model relative to the *perceived* market value of cellulosic ethanol. Figure 4 shows the impact of adding small, medium, and large grants to the strike prices estimated by the cashflow model. The grants reduce the viable price for fuels from the baseline case, although the exact trend depends on the ratio between the CAPEX and the variable costs for the project in question. For example, a project with very low CAPEX costs and debt service as a share of its strike price would see a larger decline in strike price relative to a similar facility with a higher CAPEX. Notably, none of the projects modeled approached the market value of ethanol, even with a $40 million grant. For any of the projects to reach the $2.23/GGE threshold for viability, funding would need to be saved for several years to award larger grants.

To determine the cost–benefit of upfront capital grants, we assessed the necessary funding needed for a project to meet the $2.23/GGE market value of cellulosic ethanol. As discussed above, the level of funding necessary would exceed the CAPEX of the project to offset some of the variable costs also. Our analysis indicated that for the most efficient bolt-on facility in the cashflow model, $22 million of capital grants would be necessary to bring down the strike price to $2.23/GGE. For the most efficient commercial-scale project in the model, an upfront grant of $337 million was necessary to bring down the price. For each project, the benefit assumes that a full 15 years of fuel would be supported by the capital grant. This analysis considers that the full lifetime of production of the project would be attributable to the capital grant because an upfront expenditure reduces fuel costs for the entire lifetime of the project.

Results

This section presents the impact that each of the three incentive structures has on fuel prices and assesses the extent to which each one would be able to support new ultralow-carbon fuel production. To estimate the effectiveness of the CfD and capital grants, which theoretically would occur over a number of years (to account for project construction and start-up), we estimate the impact of each policy over a 10-year period. For a capital grant, the estimated benefits consider that a one-time grant supports the entire production over the project's assumed 15-year lifetime.

Overall, we find that the price guarantee offered through a CfD best mitigates the inherent investment risks associated with bringing new ultralow-carbon fuel projects into production and thus is the most cost-effective way of supporting them. The per-gallon subsidy could incentivize some new producers to enter the market; however, we find that the bulk of the support would go toward projects already in production that have a much lower barrier to participation. Lastly, the impact of capital grant funding was found to be questionable, because grant funding did not reduce the strike price for any single project to the level of the discounted market value for cellulosic ethanol.

This study shows that without a long-term commitment to funding the original version of the proposed per-gallon subsidy in the Very Low Carbon Fuels Incentive, its potential to support new fuel production would be limited relative to CARB's own analysis. Furthermore, without locking in a commitment to the program's funding support, its perceived value by investors is likely to be far below the mid-range value cited in the CARB analysis. Like the SGBPTC, a per-gallon incentive that is only certain in the near future is inherently risky because the nominal value means very little to an investor with a project that has a 15-year project lifetime in mind. Without a structure designed to bring new entries into the market, the original subsidy, as designed, largely serves to fund existing production rather than to attract new investment.

The design of CARB's proposed per-gallon subsidy could mean that most of the program's allocated funding would go toward existing projects or those that would be built in the absence of the subsidy. Based on trends observed in E2 (2016), qualifying ultralow-carbon fuel production could rise to 97 million GGE within the next 10 years. That could mean that much of the per-gallon subsidy could go toward funding projects that do not rely on it, thus leaving relatively little funding to spur new production.

If we generously assume that all of the remaining funding goes toward fuels that could become financially viable with an additional $0.60/GGE of support, the incentive could theoretically support an additional 110 to 185 million GGE by 2026. Considering that $400 million would be spent over that time period, the cost of supporting new production would be $2.16 to $3.64 per GGE—approximately 60% higher than the subsidy's value. The high cost of support stems from the fact that much of the program's funding would be directed toward existing projects or baseline projected projects, rather than new ones encouraged by the program.

In contrast to the per-gallon subsidy, a CfD program would devote funding solely toward new production, ensuring much greater production per dollar of funding. The scenario analysis indicated that in a baseline policy mix scenario, wherein the LCFS and RFS programs continue through 2030, the CfD program would largely accrue funding because the value of the fuels from other incentives would exceed the $4.50–$5.00/GGE strike prices modeled. The program would be able to support a small, bolt-on facility at the outset and grow to fund a series of larger, commercial-scale 20 million GGE facilities by 2030. The cumulative production capacity supported would grow from 0.4 million GGE per year when the first project comes online to over 50 million GGE per year as the time series approaches 2030.

Depending on the policy mix in the scenario analysis, the CfD program could either avoid paying out in both the baseline and optimistic policy and market scenarios, or pay out an average of $0.92/GGE in the worst-case, pessimistic policy mix scenario. This indicates that in favorable policy and market climates, the program would more than pay for itself while guiding substantial new production, whereas even in the worst-case scenario, it would support new production more cost-effectively than other options. A CfD is more efficient because it pays out funding based on project need; this means that it pays out the exact amount needed to reach the strike price—no more, no less. This analysis finds that compared to other options, a CfD is better suited to supporting new and emerging technologies rather than supporting existing production, thus facilitating the production of ultralow-carbon fuels in California at a larger scale than is currently possible.

The grant-based funding approach, like the CfD, provides targeted funding to support new production. However, a grant that covers all capital costs alone does not do enough to bring down the lifetime production costs of cellulosic ethanol to align it with either the market value of cellulosic ethanol or of fossil fuels. Therefore, we estimate the total amount of funding needed to offset both fixed and variable costs to bring down the viable price of production to meet the market value of ethanol of $2.23/GGE. This commitment was $23 million for a small, bolt-on project with a capacity of 1.4 million GGE and $337 million for a larger, commercial-scale project with a capacity of 20 million GGE. Considering a lifetime production of 32.8 million and 218 million GGE for each project, respectively, the capital grant supported a relatively large amount of new production, although at a high cost. On a per-GGE basis, the cost is $0.70/GGE for a small project and $1.54/GGE for a commercial-scale one.

Table 5 summarizes the results for each of the three financing mechanisms and shows the effectiveness of each at mitigating GHG emissions. Of the three financing mechanisms, CfDs are the most effective by being able to support significant production with the lowest costs. The per-gallon subsidy is relatively expensive because its effect is diluted by the high spending on existing and baseline projected fuel production. We find that capital grants are cost-effective for smaller, bolt-on projects, although the volumes of fuel supported are much smaller than other options. This indicates that although supporting these projects may be efficient, the volumes of newly supported fuel enabled would be highly constrained by the limited number of opportunities to add bolt-on facilities to existing corn ethanol plants in California, as well as by the small production volumes of these bolt-on additions. On a commercial scale, capital grants necessitate significant amounts of upfront funding and are less efficient at encouraging high production compared with CfDs.

Table 5. Cost–Benefit Comparison

Policy	Total New Production Supported (Million GGE)	Cost ($/ GGE)	Cost of GHG Reduction ($/ton CO_2e)
Per-Gallon Subsidy	110 to 185	$2.16 to $3.64	$384 to $647
Contracts for Difference	113 to 133	$0.00 to $0.92	$0 to $148
Capital Grant (bolt-on project)	33	$0.70	$125
Capital Grant (commercial-scale project)	218	$1.54	$275

Conclusion

This study uses a cost–benefit analysis to determine which type of financial incentive provides the most cost-efficient financing to support new production of ultralow-carbon fuels in California. The analysis indicates that a CfD policy would be able to support the same level of production as other incentives, but at a much lower cost. This conclusion largely rests on two factors: (1) the CfD program is better positioned to leverage the funding of other, existing incentives to increase the market value of supported fuels relative to the strike price and thus minimize payouts; and (2) the CfD program is designed to support new production and thus pays out funds only to projects developed in conjunction with the program's support.

Our analysis shows that the other two incentive strategies, a per-gallon subsidy and grant funding, did not support new production as cost-effectively as a long-term CfD guarantee. A per-gallon approach would largely support existing production without providing the necessary long-term certainty to spur new entries into the market. Existing ultralow-carbon fuel production, as well as the projects expected to begin production in the absence of the subsidy, would increasingly use up the annual funding, leaving little available to spur new production. This means that much of the $40 million would go toward projects that do not rely on the subsidy for support, thus diluting its effect. Even if we assume that this type of incentive would support some new production, the number of new gallons supported per dollar spent is low because much of the incentive supports existing production and because a flat $1/gallon is provided even if the actual amount of support needed to reach cost parity is less than that. The lack of long-term policy certainty associated with a per-gallon subsidy as originally proposed in the CARB discussion documents would also only incentivize new ultralow-carbon fuel production at the margins, such as from corn oil or biogas, and would send a weak signal for investment in advanced technologies at commercial scales.

Our analysis suggests that capital grants would need to offset CAPEX and a share of variable costs for cellulosic ethanol projects to make the finished fuel competitive with the market value of ethanol. Smaller projects, such as bolt-on additions to existing, first-generation projects benefitted more from capital grants because they have lower capital costs. However, the potential impact of providing grants to these types of projects in California is limited by their small size and the relatively small number of first-generation corn ethanol plants in the state. Larger, commercial-scale projects required substantially higher capital grants to reduce their viable prices, leading to a relatively high cost–benefit ratio that was between the CfD and per-gallon subsidy in terms of effectiveness. Furthermore, providing grants on the scale needed to reduce prices for commercial-scale projects could necessitate hundreds of millions of dollars of upfront funding, potentially posing a big risk for policymakers.

The results from the cashflow model suggest that there are several different projects that could be viable, because their costs were below or near $5.00 per GGE of fuel. This indicates that the sum of existing incentives, such as RINs and LCFS credits, if taken at their nominal value, approaches or exceeds the viable market values for those projects estimated in the model. Implementing a CfD would leverage those existing policies to finance new production and could prove efficient and cost-effective, accruing program funding over time as the payouts to projects fall short of the annual $40 million program funding. This would allow the program to grow over time and support larger projects by 2030 and bridge the gap toward commercial-scale production of ultralow-carbon fuels. A CfD approach is the most effective incentive studied precisely because it addresses the root uncertainty of other incentives and spends less money by providing targeted payments only when necessary.

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Annex A. Modeling Assumptions

This section summarizes the key inputs into the cashflow model. For each input, this section provides a brief overview of how it is defined and how it fits into the analysis, along with the documented source for that input.

Table 6. Summary of High-Level Inputs in the Cashflow Model

Input	Value	Description	Source
Bolt-On Project CAPEX	$8.5 to $104.5 million	Estimated capital costs for additions to existing, first-generation cellulosic ethanol facilities in the United States.	Biofuels Digest, (2014); Dreeszen (2014)
Commercial-Scale CAPEX	$95 to $550 million	Estimated capital costs from Peters et al. (2016) for planned, existing, and proposed cellulosic ethanol facilities worldwide (converted to USD).	Peters et al. (2016)
Construction Time	2 years (Bolt-On) 3 years (Commercial-Scale)	Estimated construction time for each of the projects in question. For smaller, bolt-on additions to existing first-generation facilities, we estimate a shorter construction time.	Peters et al. (2016)
Start-Up Time	2 years (Bolt-On) 3 years (Commercial-Scale)	This analysis uses an assumption wherein each project engages in a ramp up of production from the end of construction through to reaching full capacity. This assumption of 50% production capacity was informed by observed start-up phases for commercial-scale projects in the United States that did not reach full production immediately.	POET-DSM (2016)
Operational Lifetime	16 years (Bolt-On) 15 years (Commercial-Scale)	This is the estimated production period for each the projects in question. For smaller, bolt-on additions to existing first-generation facilities, we estimate that they have an additional year of production to compensate for the shorter construction period.	Peters et al. (2016)
Operating Time	7,884 hours/year	Derived from the assumption that each facility has a 90% uptime, multiplied by 365 days and 24 hours. This estimate of operational hours is used to determine electricity generation for each project.	Peters et al. (2016)
Interest Rate on Debt	8%	Annual interest paid for upfront capital expenses financed through debt	Bole et al. (2010)
Required Return on Equity	15%	Return on equity used to finance upfront capital expenses. This value is used as an interest rate to calculate the weighted average cost of capital.	Bole et al. (2010)
Debt vs. Equity Split	60/40	Middle-range assumption of amount of debt vs. equity used to finance construction of a new cellulosic ethanol project	Bole et al. (2010)
Weighted-Average Cost of Capital (WACC)	10.8%	Weighted average of debt interest and required return on equity	Calculation from above data
Inflation Rate	1.2%	Annual U.S. inflation rate, based on last 5 years of annual inflation	Assumption
Feedstock cost	$84.40/tonne ($59.53 to $109.38/tonne range)	Per-tonne cost of corn stover in California. The Cashflow model also contains feedstock costs for wheat straw, rice straw, and woody biomass, but used this value for the calculations in this report. This value is used to estimate the variable costs associated with cellulosic ethanol production.	Calculations from values provided by Kaye (2014) and Lux Research, Inc (2016)
Project Yield	76 gallons/tonne feedstock (52.9 to 100.3 range)	This value is used to determine how much of each chemical is used for each project, based on the chemical demand per gallon of produced ethanol, and feedstock consumption for each project.	Humbird et al. (2011)

Input	Value	Description	Source
Yeast Price	$0.10/gallon	Price of chemicals used for cellulosic ethanol conversion process. Used to estimate the variable costs associated with cellulosic ethanol production.	Humbird et al. (2011)
Ammonia Price	$0.06/gallon	Price of chemicals used for cellulosic ethanol conversion process. Used to estimate the variable costs associated with cellulosic ethanol production.	Humbird et al. (2011)
Cellulase Price	$0.48/gallon	Price of chemicals used for cellulosic ethanol conversion process. Used to estimate the variable costs associated with cellulosic ethanol production.	Humbird et al. (2011)
Sulfuric Acid Price	$0.03/gallon	Price of chemicals used for cellulosic ethanol conversion process. Used to estimate the variable costs associated with cellulosic ethanol production.	Humbird et al. (2011)
Electricity Generation	13 MWh	Several projects in the Peters et al. (2016) data set have project-specific electricity generation rates from the on-site combustion of byproducts from cellulosic ethanol conversion. For all other projects, we assume the “general” 13 MWh estimate used in the study. For small, bolt-on additions to first-generation facilities, we assume that residues stay with the parent facility and their combustion is not attributable to the bolt-on.	Peters et al. (2016)
Electricity Sales Price	0.032 $/kWh	Average net metering price for 2016 in California	San Diego Gas and Electric (2016)