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April 23, 2018

Mr. Samuel Wade
Branch Chief, Transportation Fuels Branch
Industrial Strategies Division
California Air Resources Board
P.O Box 2815
Sacramento, CA 95812

Submitted electronically at: http://www.arb.ca.gov/lispub/comm/bclist.php

Re**:** Comments on the 2018 Amendments to the Low Carbon Fuel Standard

Dear Mr. Wade:

Airlines for America[1] (A4A) would like to thank the California Air Resources Board (CARB) for the opportunity to comment on its proposed amendments to the Low Carbon Fuel Standard (LCFS). As detailed below, A4A and its member airlines strongly support the inclusion of alternative jet fuel (AJF) as an eligible credit-generating fuel on an opt-in basis. Such an approach would provide needed regulatory incentives for AJF, support the developing California advanced biofuels industry, lower the cost of compliance for obligated parties, and advance the State's environmental goals. Accordingly, while we propose a few changes to the carbon intensity provisions that would apply to AJF, we support CARB's proposal to add AJF as an LCFS credit-generating fuel and appreciate the extensive work CARB staff members have done on this proposal.

I. <u>A4A, AJF and Significant Emissions Benefits from AJF as an Eligible Credit-Generating Fuel under the California LCFS</u>

By way of background, A4A and its members are part of a global aviation coalition that has committed to a 1.5% annual average fuel efficiency improvement through 2020 and carbon neutral growth from 2020, subject to critical aviation infrastructure and technology advances achieved by government and industry. The initiatives our airlines are undertaking to further address greenhouse gas (GHG) emissions are designed to responsibly and effectively limit their fuel consumption, GHG contribution, and potential climate change impacts, while allowing commercial aviation to continue to serve as a key contributor to the U.S. and local economies. At the same time, we continue to build upon our strong record of reducing conventional air pollutant emissions.

The availability of sustainable AJF in significant quantities is a key pillar to the achievement of the industry's goals, and A4A and its members are working hard to lay the groundwork for the establishment of a sustainable AJF industry. AJF is particularly critical to the aviation industry's decarbonization strategy

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[1] A4A is the principal trade and service organization of the U.S. scheduled airline industry. A4A members are Alaska Airlines, Inc.; American Airlines, Inc.; Atlas Air, Inc..; Federal Express Corporation.; Hawaiian Airlines; JetBlue Airways Corp.; Southwest Airlines Co.; United Continental Holdings, Inc.; and United Parcel Service Co. Air Canada is an associate member.

as aviation, unlike ground transportation, cannot electrify in the near-term and is therefore reliant upon liquid fuels.

There is particularly great interest among biofuel producers and A4A members in producing and utilizing sustainable AJF in the California market. United Airlines began using commercial quantities of AJF at Los Angeles International Airport in 2016 pursuant to an off-take agreement with AltAir Fuels to purchase of up to 15 million gallons of AJF over 3 years. United has also made a $30 million equity investment in Fulcrum BioEnergy that includes provisions to co-develop up to five facilities and purchase at least 90 million gallons of AJF per year over ten years. FedEx and Southwest Airlines have similarly committed to each purchase 3 million gallons per year from Red Rock Biofuels for expected use in Northern California, and JetBlue has signed a 10-year off-take agreement with SG Preston for up to 10 million gallons of AJF per year. As the AJF industry continues to mature, these and other member airlines are actively exploring additional agreements, and the prospect of an LCFS credit for AJF is an important economic factor in these agreements.

As A4A has noted previously, allowing AJF producers to generate LCFS credits would significantly improve the economics of new and existing facilities by allowing them to generate credits from all transportation fuels produced. The AltAir facility, as well as other potential AJF facilities, necessarily produces both renewable diesel and AJF, along with other products. Given that the LCFS is intended to spur investment in the entire renewable fuels industry, we encourage CARB to strengthen this investment signal by allowing LCFS credit for all low carbon transportation fuels.

Incentivizing the production of AJF is particularly appropriate in light of the critical role the airline industry can play in helping to obtain financing for facilities through dedicated off-take agreements, a role that the airline industry is uniquely situated to fill. Modeling conducted for A4A by the National Renewable Energy Laboratory (NREL) pursuant to NREL's Biomass Scenario Model demonstrates the synergistic relationship that airline off-take agreements can have when coupled with access to credit markets like the LCFS. Notably, NREL's modeling indicates that an additional credit for AJF would likely result in significantly increased production of both AJF and renewable diesel.[2]

CARB's proposal to add AJF as a credit-generating fuel would also lower compliance costs for regulated parties and is consistent with ARB Resolution 11-39, which seeks to explore the "expansion of the LCFS credit trading market" and "incorporation of a flexible compliance mechanism . . . ."[3] Including AJF in the LCFS credit trading market enlarges the pool of credits available to obligated parties further promoting cost containment. In addition, crediting AJF would assist in lower compliance costs by providing an additional avenue for low carbon fuel use that is unaffected by the blending constraints imposed on ground transportation fuels.

Crediting AJF on an opt-in basis in the LCFS also advances California's environmental goals. Promoting the use of AJF will not only support the State's GHG reduction targets, it would also provide substantial co-benefits through reductions in conventional air pollutant emissions. While CARB already reports in its Initial Statement of Reasons (ISOR) that AJF can provide both nitrogen oxide (NOx) and particulate matter (PM) reductions,[4] a comprehensive assessment under the Transportation Research Board's Airport Cooperative Research Program (ACRP) confirms that the use of AJF can reduce emissions of sulfur oxides (SOx), PM, carbon monoxide, unburned hydrocarbon emissions, and NOx to varying

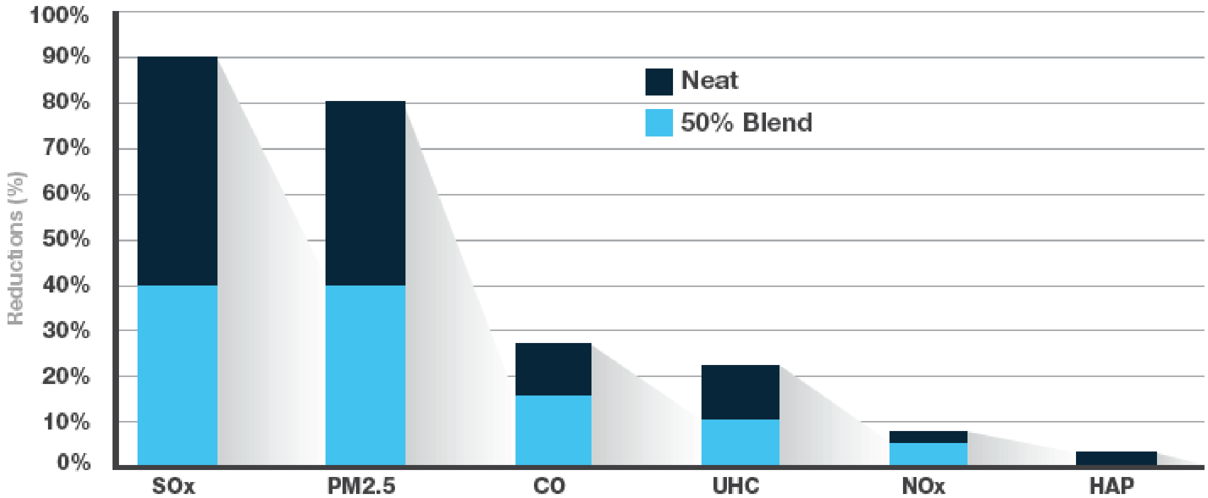
[2] *See* National Renewable Energy Laboratory, "Effect of Additional Incentives for Aviation Biofuels: Results from the Biomass Scenario Model," presented at CARB's March 17, 2017, public working meeting (NREL presentation) (attached hereto).

[3] *See* Resolution 11-39, Amendments to the Low Carbon Fuel Standard Regulation at 9 (Dec. 16, 2011).

[4] CARB, Staff Report: Initial Statement of Reasons at V-18–20 (Mar. 6, 2018) (CARB ISOR).

degrees, with reductions in SOx and PM being particularly dramatic.[5] The results of this assessment are illustrated in Figure 1 below. Thus, AJF could be used to strategically target airports like Los Angeles International Airport that are located in air basins facing significant air quality challenges, which gives AJF an advantage as an air quality improvement measure over its on-road counterparts which are more widely distributed statewide.

Figure 1. The Airport Cooperative Research Program Project 02-80: Representative Air Pollution Emission Reduction from the Use of Sustainable Alternative Jet Fuel



Moreover, as CARB points out in its ISOR, the reductions in emissions with local air quality impact that accompany the carbon emissions reductions incentivized by the LCFS also support the goal established by the California Environmental Justice Advisory Committee (EJAC) "for the State to provide and facilitate 'access to clean transportation technologies'" as means of advancing the State's environmental justice goals.[6] Airports are major hubs of economic activity, with emissions from that activity reaching nearby communities. Unfortunately, residences in close proximity to airports may be disproportionately disadvantaged, in terms of socioeconomic impact and/or environmental impacts. This assertion is particularly evident in California where Los Angeles International Airport is located in a CalEPA-designated disadvantaged community; San Jose and San Francisco International Airports are both located next to CalEPA-designated disadvantaged communities; San Diego International Airport is located next to a CalEPA-designated low income community; and Sacramento International, Santa Monica Municipal, and John Wayne Airports are located next to Cal-EPA designated disadvantaged and low-income communities.

While the reduction any emissions with local air quality impacts that result from the addition of AJF as a credit-generating fuel under the LCFS will help California meet its environmental justice goals, CARB highlights PM reductions from AJF as an important example:

> CARB staff has also heard concerns about particulate emissions from the residents of disadvantaged communities living near airports. Since airports and aviation fall under federal regulatory jurisdiction, incentivizing the use of cleaner jet fuels with fewer emissions than

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[5] *See* Transportation Research Board, *ACRP Project 02-80: State of Industry Report on Air Quality Emissions from Sustainable Alternative Jet Fuels* at 5 (April 2018) (available at http://www.trb.org/Aviation1/Blurbs/177509.aspx).

[6] CARB ISOR at VII-5 (citing to AB 32 EJAC Recommendations for Proposed 2017 Scoping Plan Update).

> traditional jet fuels is one way California is helping residents near these facilities. The proposed amendments will permit alternative jet fuels to generate LCFS credits, thus incentivizing their use and yielding the accompanying PM reduction co-benefits. These emissions reductions are greatest during landings, take-offs, and the taxiing of the plane on the airstrip; providing direct PM emissions reductions to the residents of communities near airports.[7]

Indeed, CARB's AJF proposal will bring synergistic local air quality benefits in the vicinity of airports, benefitting disadvantaged communities nearby.

Because crediting AJF in the LCFS would provide needed regulatory incentives for AJF, support the developing California advanced biofuels industry, lower the cost of compliance for obligated parties, and advance the State's environmental and environmental justice goals, A4A strongly urges CARB to adopt the proposed amendments to the LCFS program. In addition, we offer the following specific comments on various aspects of CARB's proposal.

II. <u>A4A Supports CARB's Proposal for AJF as a Credit-Generating Fuel, Without a Mandate</u>

A4A agrees with CARB's general exemption of aircraft fuels from the LCFS mandate. Subjecting aircraft fuels to annual carbon intensity standards would raise federal preemption issues and would not be appropriate given the rigorous jet fuel specifications that make producing jet fuels a "higher hurdle" than producing ground-based fuels. That said, we strongly support CARB's proposal to *incentivize* the use of AJF in aircraft by allowing a voluntary, opt-in credit for such fuels. By promoting the production and use of AJF, CARB would not cross into federal regulatory jurisdiction but rather would provide airlines an opportunity to better support the State's GHG goals. Furthermore, the proposal is fully in line with the U.S. Environmental Protection Agency's approach under the Renewable Fuel Standard (RFS): the RFS explicitly allows for the generation of Renewable Identification Numbers for the production of AJF without mandating the use of any particular volume of AJF.

III. <u>A4A Urges CARB to Adjust the 2010 Conventional Jet Fuel Baseline Upward</u>

We suggest that CARB revisit the proposed 2010 value for the conventional jet fuel baseline, which currently is proposed to be set at 89.75 g CO_2e/MJ, to more accurately reflect refinery efficiency in California. Several recent analyses indicate that the jet fuel refining efficiency assumption in the California GREET model is overly optimistic. For example, the "AJF Producers" group has prepared and submitted analyses under the CA-GREET 3.0 spreadsheet model demonstrating that 94.04 g CO_2e/MJ would be an appropriate carbon intensity value for AJF.[8] We urge CARB to appropriately adjust the efficiency assumption consistent with these analyses, which would result in an upward adjustment relative to the proposed 2010 value for the conventional jet fuel baseline.

IV. <u>The Proposal to Have Decreasing Carbon Intensity Benchmarks for AJF Should Be Revised</u>

Table 3 of the CARB's Proposed Regulation Order provides decreasing carbon intensity benchmarks for 2019–2030 for fuels used as substitutes for conventional jet fuel. According to the ISOR, "the AJF annual benchmarks are anchored to the 2010 baseline [carbon intensity] for conventional jet fuel and incorporate the same annual percent reductions as the benchmarks for gasoline and diesel."[9] Based on this, CARB

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[7] CARB ISOR at VII-7 and VII-8.

[8] Specifically, the AJF Producers' analysis demonstrates that the appropriate refining efficiency for use in setting the AJF baseline should be 91.1%, which results in a corresponding baseline carbon intensity for conventional jet fuel at 94.04 gCO_2e/MJ. We also note that previous CARB technical work fully supported a jet fuel baseline at 93.3 g CO_2e/MJ, which CARB specified for use in the above-mentioned modeling analysis conducted by NREL. *See* NREL presentation at 18 (noting CARB specified CI values of 93.3, 102, and 99.8 for petroleum jet, diesel, and gasoline, respectively).

[9] CARB ISOR at II-5.

proposes to adjust the proposed 2010 carbon intensity baseline of 89.84 g CO_2e/MJ for jet fuel to 84.23 g CO_2e/MJ for the 2019 start date of the proposed opt-in credit and decrease the carbon intensity further thereafter. A4A does not believe it is appropriate for CARB to apply decreasing carbon intensity benchmarks to jet fuel and urges CARB to reconsider this aspect of its proposed amendments.

The LCFS and its proposed amendments have no regulatory mandate to reduce the carbon intensity of jet fuel over time unlike the requirements for diesel and gasoline to reduce their respective carbon intensities 7% and 8% by 2020 and 20% for both fuels by 2030.[10] Removing the decreasing carbon intensity benchmarks for jet fuel would be consistent with the fuel's existing exemption and would appropriately recognize the difference between CARB's regulatory authority over diesel and gasoline and its limited authority to offer incentives to reduce aviation emissions.[11] Notably, crediting AJF on an opt-in basis in the LCFS still assures environmental benefit even with a static baseline relative to conventional jet fuel, as the AJF would have to have confirmed emissions reductions relative to that baseline to be credited.

A4A understands that CARB is considering decreasing the carbon intensity benchmark over time for AJF out of a potential concern by some that the absence of a decreasing benchmark could distort the alternative fuels market in favor of AJF over similar and competing ground transportation fuels like renewable diesel. To the contrary, however, decreasing the carbon intensity benchmark for jet fuel is not needed to prevent market distortions given the many factors that will still place AJF at a market disadvantage, and the fact that AJF production also necessarily results in the production of other fuels within a product slate.

There are at least three reasons why AJF is and is expected to remain at a market disadvantage relative to alternative ground transportation fuels. First, outside market forces encourage renewable diesel production over AJF. The chief market force favoring diesel over jet fuel is the higher price historically commanded for diesel fuel in the spot market. Data from the U.S. Energy Information Administration (EIA) indicates that the spot price for jet fuel has historically been below the price of diesel, and the EIA anticipates this market dynamic to continue for the foreseeable future, chiefly due to tighter sulfur limits on diesel fuel (see Figure 2 below).[12] Average annual data on the prices of diesel and jet fuel available in Los Angeles summarized below in Figure 3 also demonstrate that the price of diesel in California generally exceeds the jet fuel price.[13]

[10] CARB ISOR, App. A at § 95484(b), (c).

[11] As noted above, California is preempted from regulating jet fuel and therefore has no legal basis to require carbon intensity reductions from the conventional jet fuel pool despite its authority to incentivize AJF through a voluntary credit as proposed.

[12] See U.S. Energy Information Administration spot price data at https://www.eia.gov/dnav/pet/pet_pri_spt_s1_d.htm; *see also* EIA, *The Flight Paths for Biojet Fuel* at 3 (noting that "non-petroleum hydrocarbons that can go into jet fuel can also be blended into diesel fuel or heating oil, both of which are projected to sell for higher prices than jet fuel in the future."). *See also*, International Renewable Energy Agency, *Biofuels for Aviation* at 5 (noting that producers are focused on producing renewable diesel, which has a larger market and higher sales price).

[13] Data provided by Bloomberg.

Figure 2. EIA estimates and projections of U.S. jet fuel and distillate fuel prices, 2000—2040

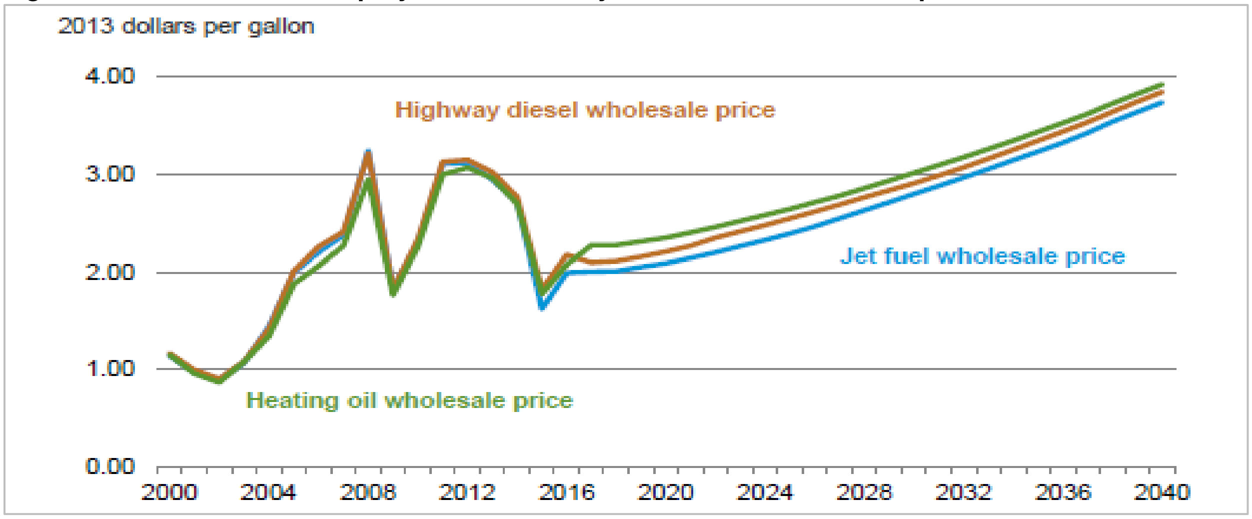
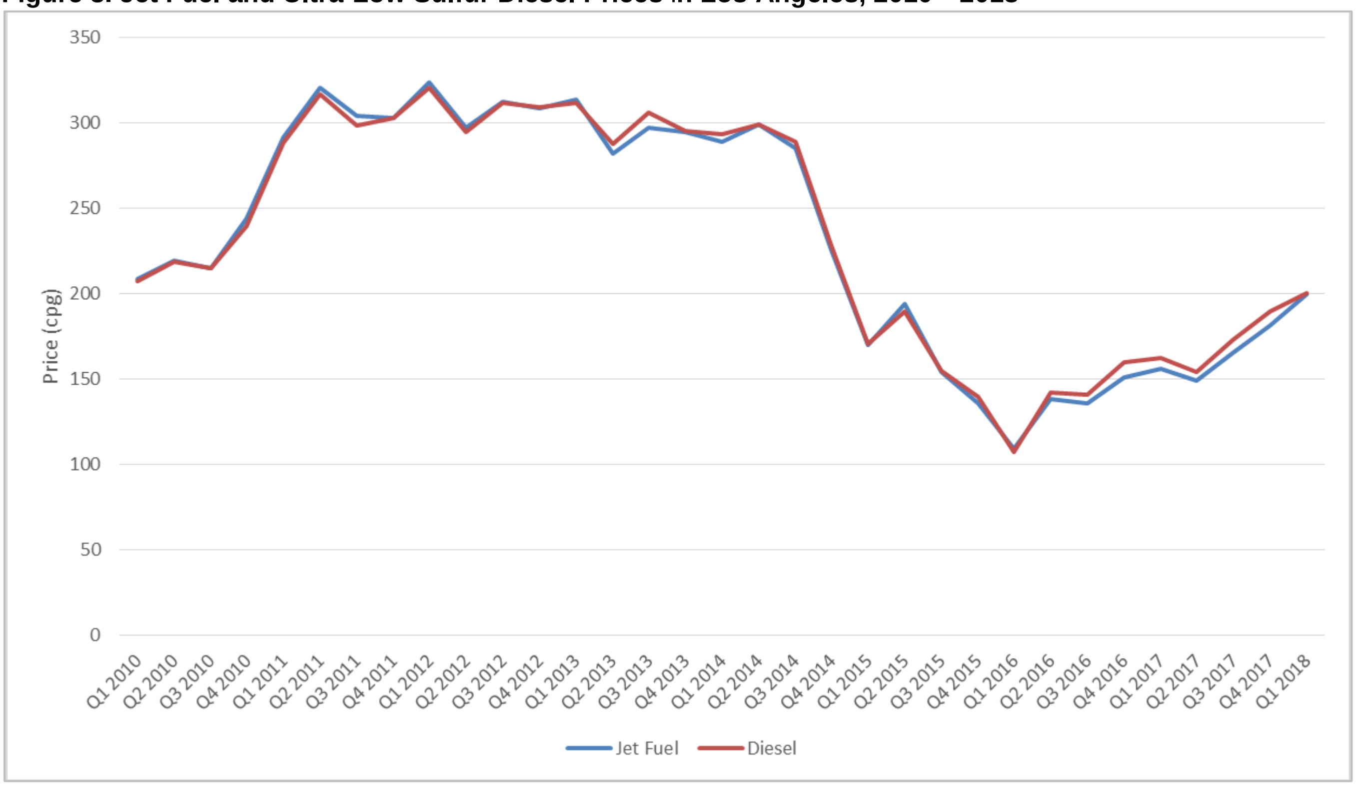


Figure 3. Jet Fuel and Ultra-Low Sulfur Diesel Prices in Los Angeles, 2010—2018



Second, diesel substitutes benefit from the added value associated with diesel's inclusion in the California cap and trade program (currently $15/ton or roughly 15 cents per gallon of diesel) which promotes renewable diesel supply. This pricing benefit and the higher handling costs associated with meeting strict aviation fuel specifications make jet fuel a less economical option.

Third, the significant differences between the proposed 2010 baselines of 89.84 g CO_2e/MJ for jet fuel, which CARB proposes to adjust to 84.23 g CO_2e/MJ for the 2019 start date of the proposed opt-in—or even the revised baseline of 94.04 g CO_2e/MJ that the AJF Fuel Producers and A4A assert—and 100.95 g CO_2e/MJ for diesel further favor diesel. In fact, the proposed jet fuel baseline is already significantly below the current carbon intensity standard for diesel of 96.91 g CO_2e/MJ[14] and would remain below the diesel standard for years. CARB should consider alternative benchmarks that would not unintentionally memorialize existing structural disincentives for the production of AJF.

A4A therefore suggests that CARB use a static carbon intensity benchmark instead. Using a static baseline would recognize jet fuel's status as an exempt fuel receiving opt-in credit for AJF use. It would also maximize CARB's ability to generate emissions reductions in a sector where CARB otherwise does not have regulatory authority.

Furthermore, the question of parity between a static jet fuel baseline at the level currently proposed and the diesel carbon intensity baseline would not even become an issue until later years (for example, 2024 or 2027, depending on what initial baseline is used for jet fuel). And, even then, the other market forces disadvantaging AJF would remain. Moreover, the fact that diesel is necessarily coproduced with AJF, often with diesel in a much higher ratio, assures its prominence in the market. CARB has recognized that it is unlikely that promotion of AJF will divert investment away from diesel. In its ISOR, some stakeholders expressed concern that "if supply of low carbon biomass feedstocks is limited, AJF production may compete with production and on-road use of biomass-based diesels. . . ."[15] However, CARB "Staff believes this is unlikely and that a more likely outcome of the Proposed Amendments' inclusion of AJF is that more facilities would be built that co-produce both biomass-based diesel and AJF . . . ."[16] We urge CARB to reinforce this finding based on the above information.

For these reasons, CARB is perfectly justified in maintaining a static carbon intensity baseline for AJF as A4A suggests. Nonetheless, should CARB not do so, it should at least adopt a static baseline for jet fuel until such time that the jet fuel carbon intensity baseline meets the diesel carbon intensity benchmark, at which time the jet fuel carbon intensity benchmarks would decrease in line with the diesel carbon intensity benchmarks. This would ensure that AJF never commands a greater LCFS credit than renewable diesel and would promote market parity and the fuel neutrality goals of CARB.

A4A supports CARB's intent to eliminate potential market distortions under the LCFS. Indeed, eliminating market distortions is precisely why A4A has consistently urged CARB to include AJF as an opt-in fuel under the LCFS. However, we urge CARB to closely examine options that would protect against market distortions while maximizing the LCFS market signal and the emissions reduction potential of the program. Consequently, we urge CARB to reconsider its carbon intensity benchmarks for jet fuel in favor of one of the two approaches we have outlined above, which reflect CARB's own regulatory authority and policy goals.

V. CARB's Environmental Analysis Confirms Environmental Benefit

A4A outlined the extensive GHG emissions benefits and local air quality emissions benefits in Section I of these comments. Further, we expressly support CARB's conclusion in the Draft Environmental Assessment, conducted pursuant to 17 CCR 6005, that "[w]ithout the use of AJFs, it could be difficult to achieve long-term GHG emission reduction goals . . ."[17] in the State, and that the "likely outcome of the Proposed Amendments' inclusion of AJF is . . . that the total air quality benefit increases."[18] As noted

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[14] CARB ISOR, App. A at § 95484(c) (carbon intensity for 2018).

[15] CARB ISOR, App. D: Draft Environmental Analysis at 66–67.

[16] *Id.*

[17] *Id.* at 207.

[18] *Id.* at 67.

above, independent analysis by NREL and ACRP confirm the reduction in criteria pollutant emissions from use of AJF.

VI. CARB Has Appropriately Captured the Definition of Alternative Jet Fuel

A4A further supports CARB's proposed definition of alternative jet fuel in Section 95481.[19] Since the LCFS, by definition, is not limited to renewable fuels, the definition of AJF should be sufficiently broad to allow for numerous low carbon alternative jet fuels from either biogenic or non-biogenic feedstocks, including waste industrial gases that would otherwise be emitted. CARB's proposed definition accomplishes this aim, and, therefore, A4A supports the definition as proposed.

VII. Producers/Importers as Fuel Reporting Entities

We also support CARB's proposal to designate the reporting entity as the producer or importer of fuel that is delivered to the storage facility from which it will be uploaded for use in California.[20] A4A believes it is appropriate for CARB to presume that AJF delivered to the pipeline or the airport and designated for use in California will ultimately be uplifted. Furthermore, the designation is consistent with the treatment of other fuels under the LCFS, eliminates potential administrative complexities relating to verifying that fuel sold in California will be ultimately uploaded in the state, and avoids unnecessary reporting of conventional jet fuel for blends. Consequently, we support CARB's proposal as is.

* * * * *

Thank you for your consideration. Please let us know if you have any questions regarding our comments or would like to discuss them in greater detail.

Sincerely,

Veronica Bradley Manager Environmental Affairs Airlines for America	Nancy N. Young Vice President Environmental Affairs Airlines for America

Attachment

[19] CARB ISOR, App. A at § 95481(a)(6).

[20] *Id.* at § 95483(a)(1)(C).

Effect of Additional Incentives for Aviation Biofuel:

Results from the Biomass Scenario Model

Laura Vimmerstedt and Emily Newes, NREL

Presentation for the Public Working Meeting to Discuss Potentially Including Alternative Jet Fuel in the Low Carbon Fuel Standard, March 17, 2017

Preliminary. For use by CARB.

Analysis Basis and Disclaimer

- **The data, results, and interpretations are subject to additional review and may be modified before final publication.**
- This analysis was conducted using the Biomass Scenario Model [http://www.nrel.gov/analysis/bsm/]. The Biomass Scenario Model is a dynamic model of the domestic biofuels supply chain. The Biomass Scenario Model explicitly focuses on policy issues, their feasibility, and potential side effects. It integrates resource availability, physical/technological/economic constraints, behavior, and policy. The analysis includes information and selects scenarios based on discussions with the California Air Resources Board staff, Airlines for America, and Graham Noyes on behalf of alternative jet fuel producers.
- This document has not been reviewed by technical experts beyond the National Renewable Energy Laboratory, Airlines for America, Department of Energy-Biomass Energy Technologies Office, the California Air Resources Board, and Graham Noyes on behalf of alternative jet fuel producers.
- This report was prepared as an account of work sponsored by an agency of the United States government. Neither the United States government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States government or any agency thereof.

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Introduction

- NREL: A national lab supporting U.S. Department of Energy, Biomass Energy Technologies Office (BETO)
- BETO engagement on aviation biofuels led to analysis for U.S. Department of Transportation, Federal Aviation Administration (FAA)
- Airlines for America (A4A) requested additional exploratory scenarios within FAA analytic framework
- A4A requested additional scenarios in support of California Air Resources Board (CARB) rulemaking through a Technical Services Agreement with NREL
- NREL does not advocate for or against the policies analyzed in this study

Acknowledgements

We gratefully acknowledge:

- Alex Menotti, for identifying the opportunity for this analysis, and for the financial support of Airlines for America;
- Anthy Alexiades, Katrina Castellano, James Duffy, Jiqing Fan, Jeff Kessler, and all of the CARB analysts who contributed to the data and methodology for this analysis;
- Graham Noyes, for consultation on behalf of alternative jet fuel producers;
- Alicia Lindauer and Zia Haq, DOE project managers who have contributed to the development of the Biomass Scenario Model;
- The Biomass Scenario Model project team;
- Nate Blair, Kevin Carroll, Heather Lammers, David Mooney, Robin Newmark, Gian Porro, Amy Schwab, Neil Snyder, the NREL reviewers;
- Steve Peterson, the Biomass Scenario Modeling team reviewer.

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Analysis Scope Selected in Consultation with CARB, A4A, and Representative of Alternative Jet Fuel Producers

- What would be the impact of extending to aviation biofuel a Low Carbon Fuel Standard (LCFS) credit worth $90/metric ton, starting in 2019?
- Impacts of interest include:
  - Biofuels production by conversion pathway
  - Biofuels production by product type
  - Feedstock use
- How would these impacts change under different scenarios for
  - Oil price?
  - Renewable Identification Number credit value?
  - Offtake agreements?

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Preview of Conclusions

This presentation provides context and caveats for the following conclusions:

- Under many of the conditions that we modeled, extending the LCFS to include alternative jet fuel increases production of hydrocarbons from cellulose and oil crops.
- Within the range of incentives and economic conditions that we examined, increased production appears more likely to increase production of hydrocarbons when other incentives and economic conditions for biofuels are moderately favorable, rather than when they are extremely favorable or extremely unfavorable.
- Under some conditions, extending the LCFS to jet fuel decreases production of hydrocarbons in some years, due to the dynamic market response to higher demand for cellulosic feedstocks from both hydrocarbon and ethanol pathways.
- The increases in annual biofuels production that occurred with the extension of the LCFS to jet were orders of magnitude greater, and occurred during more of the analysis conditions, than the decreases.

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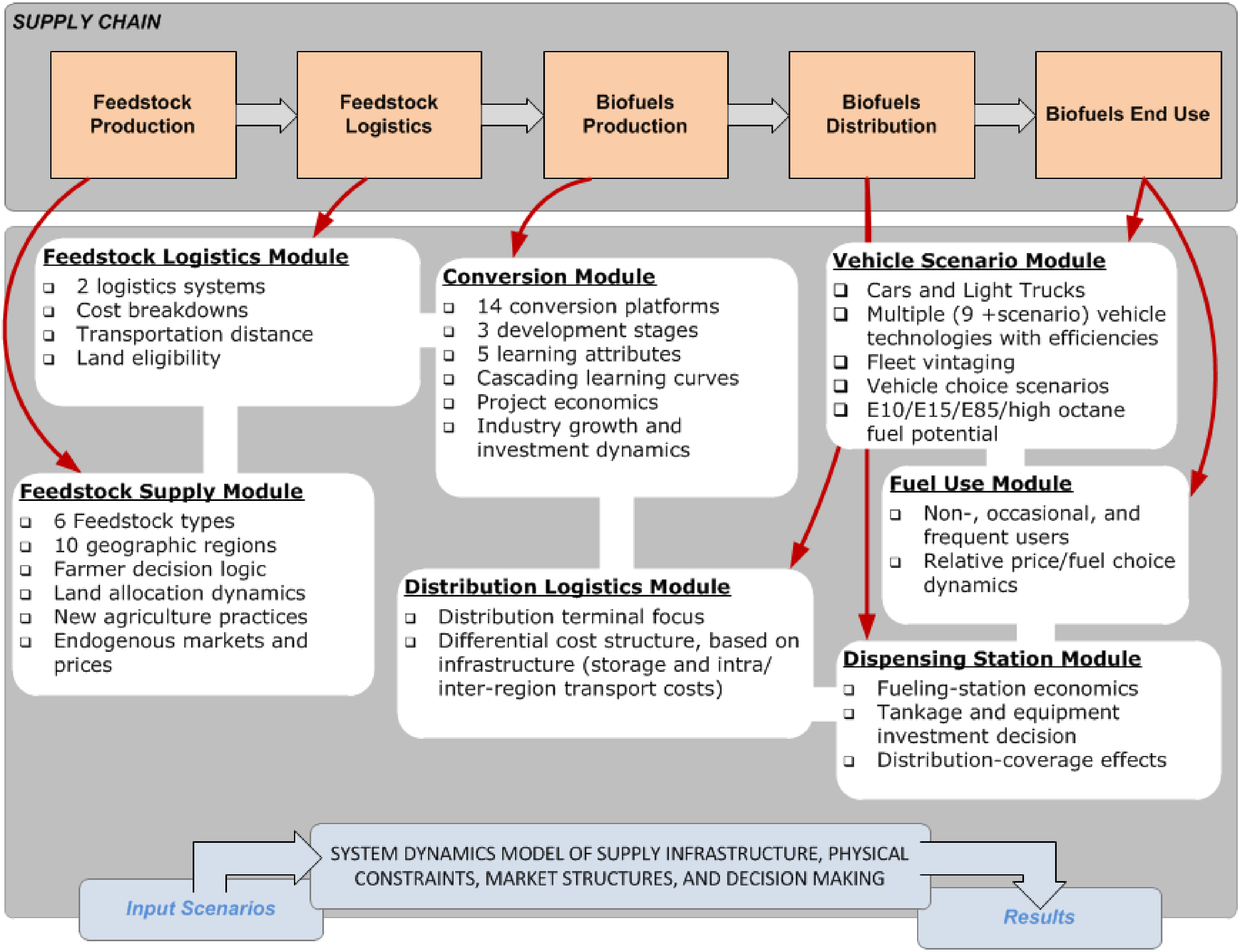
Methods

NREL Used the Biomass Scenario Model for the Analysis



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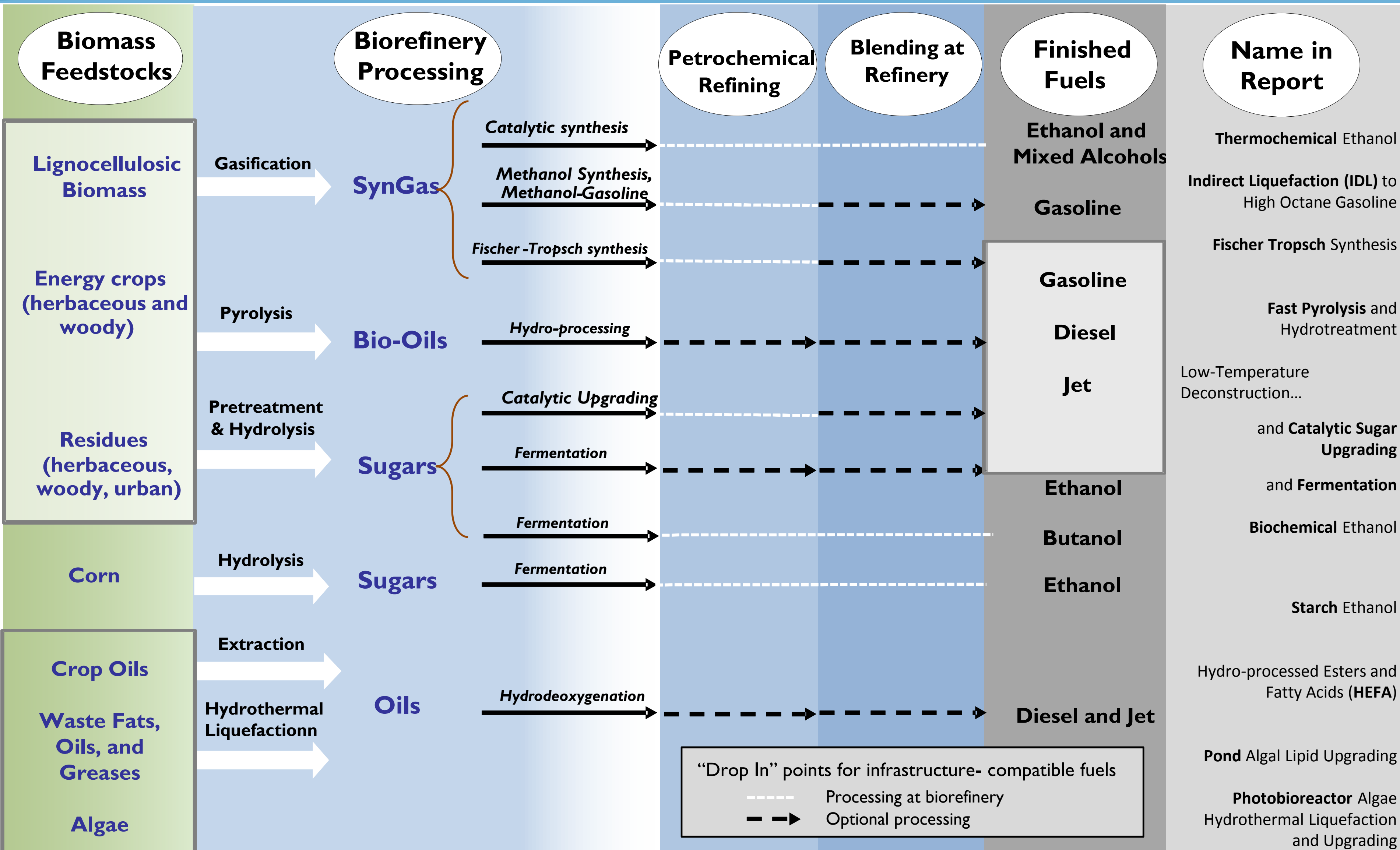
Biofuel Pathways in the Biomass Scenario Model



Modeled biofuel pathways are abstract approximations that are not representative of every facility.

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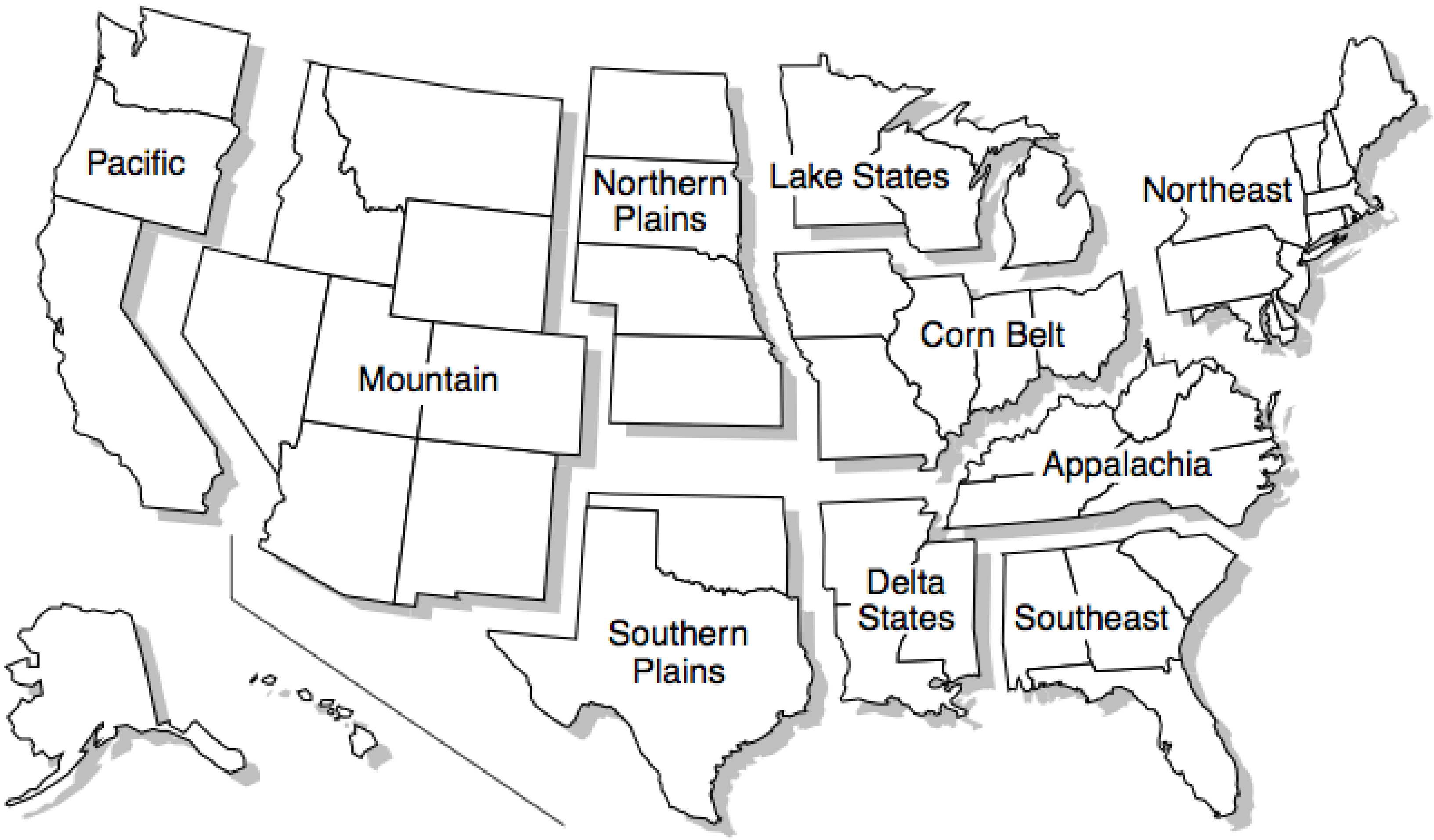
The Biomass Scenario Model Accounts for Use of Land in Contiguous U.S. by Region

Low Carbon Fuel Standard applies in Pacific region



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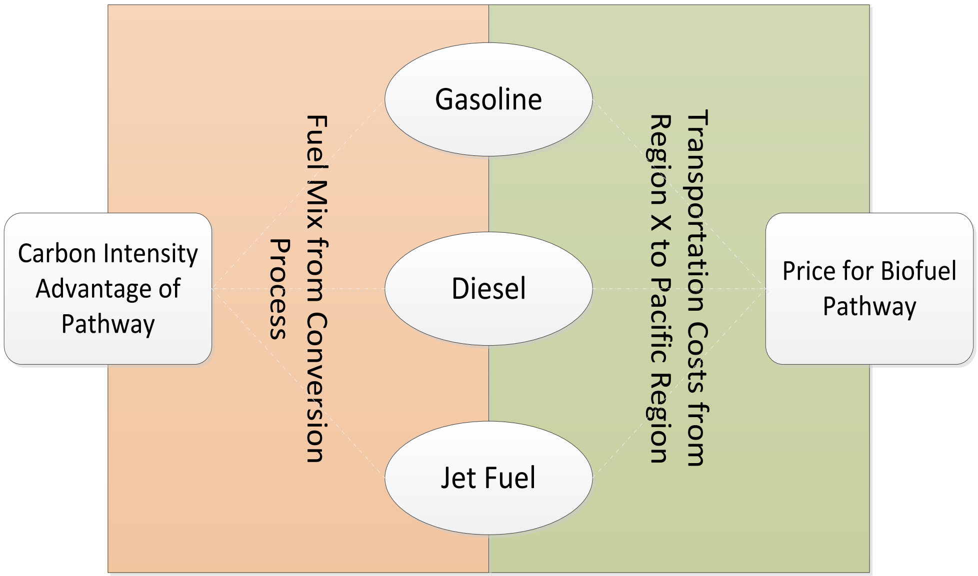
Low Carbon Fuel Standard in Pacific Region of the Biomass Scenario Model



- Calculate average carbon intensity by pathway from approved physical pathways.
- Subtract from target fossil (oil) carbon intensity.
- Apply to finished fuel covered by LCFS under given credit price.
- Estimate and apply transportation costs from biorefinery site to Pacific region.
- Apply the resulting price premium to pathway.
- This method does not include representation of price feedback in credit markets

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Assumptions

Biomass Scenario Model: Assumptions

The Biomass Scenario Model: A simulation model for scenario analysis of biomass-to-biofuels market development with detailed representation of policy, technology, resource, and investment. Two of the many key assumptions:

- Existing starch ethanol industry continues to contribute to E10 fuel supply
- Biorefinery construction is limited to 25 plants/yr, due to labor and materials constraints

This analysis used technology and resource assumptions specific to the CARB analysis:

- Product mix between gasoline, diesel, and jet fuel is constant for each production pathway
- Techno-economics are a key assumption (see subsequent slides)
- Available supply of fats, oils, and greases (FOG) is consistent with supply curves used in the study with the Federal Aviation Administration

Scenario results are contingent on the following and other design assumptions:

- How many and what type of biorefineries are operating or go into operation?
  - Existing and under construction facilities are from Warner et al. (2017)
  - Offtake agreements are modeled assuming that the contracted capacity comes online and delivers regardless of fuel price
  - Offtake capacity not under construction in Warner et al. (2017) is assumed to start construction in 2018 in core scenario
- What incentives are in place for biofuels?
  - Biomass Crop Assistance Program
  - Not in place in core scenario: Tax Credits, Loan Guarantees
  - RIN prices input as scenarios for D6 and D4 prices, with D3 price a function of oil price

Representation of Low Carbon Fuel Standard (LCFS), Renewable Identification Number (RIN), and Offtake Agreements does not include market feedbacks

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Selected Conditions for This Study

Input Assumption	Conditions
LCFS Value	\$60, \$90, \$150, or \$200/metric ton
LCFS Start Date for Jet	2019
RIN Values D6 Renewable Fuel D4 Biomass Based Diesel D3 Cellulosic Biofuels	D6: \$0, \$0.70, \$1.70 D4: \$0.32, \$0.84, \$1.70 {D4 Price} = 0.32 + 0.74*{D6 Price} D3: Calculated for each year as {D3 Price} = -1.1 + 1.11*{D4 Price} + 1.49*{Waiver.Credit}
Integrated Biorefinery Facilities	Existing and Under Construction (Warner et al. [2017])
Carbon Tax	None
Oil Price	1. AEO 2017 Reference Price 2. AEO 2017 High Oil Price
Offtake Agreements	1. Without Offtakes 2. With Offtakes starting in 2018 or 2021
Other Incentives	1. BCAP Only 2. Tax Credits + 65% or 80% Loan Guarantee
Dollar Year	2011

LCFS = Low Carbon Fuel Standard
RIN = Renewable Identification Number

AEO = Annual Energy Outlook
BCAP = Biomass Crop Assistance Program

Preliminary. For use by CARB.

Alternative Jet Fuel Techno-economic Assumptions

Selected techno-economic analysis (TEA) assumptions for nth plant performance for new plants. The current state of technology varies in progress towards nth plant. Note that several current projects are retrofits, whose costs are not reflected here.

TEA Component	Units	Hydro-processed Esters and Fatty Acids (Pearlson 2012)	Alcohol to Jet Nominal (Staples 2014)	Fischer Tropsch (Tan 2016)
Minimum Fuel Selling Price	$/gal	3.69	7.77	3.35
Process Yield	gal/ton	245.0	42.2	69.3
Fixed Capital Investment	$	145,500,000	739,478,895	580,200,000
Fixed Operating Cost	$/yr	9,816,400	91,386,820	26,510,000
Other Variable Operating Cost	$/yr	19,400,000	77,654,946	5,324,000
Coproducts Sales Revenue	$/yr	0	0	0
Power Sales Revenue	$/yr	0	0	4,470,000
Feedstock Throughput Capacity	tons/day	788	3,991	2,205
Product Yield Breakdown (max distillate case)				
Gasoline Blendstock	gal/ton	6.1	4.0	14.6
Jet Fuel Blendstock	gal/ton	38.4	35.5	49.1
Diesel Blendstock	gal/ton	199.0	2.7	5.6

Preliminary. For use by CARB.

Other Hydrocarbons Techno-economic Assumptions

		Fast Pyrolysis	Methanol to Gasoline	Catalytic Upgrading of Sugars	Fermentation	Algae
TEA Component	**Units**	w/ Upgrading (Jones et al. 2013)	Methanol to high octane gasoline (Tan et al, 2015)	Catalytic Upgrading (Davis 2015)	Biological to Hydrocarbons (Davis 2013)	[Pond] Algae (Davis et al. 2014)
Minimum Fuel Selling Price	**$/gal**	3.39	3.25	4.05	5.35	4.35
Process Yield	**gal/ton**	83.6	64.9	77.7	43.3	141.1
Fixed Capital Investment	**$**	665,200,000	415,200,000	626,500,000	553,200,000	436,100,000
Fixed Operating Cost	**$/yr**	33,600,000	20,600,000	16,100,000	14,080,000	13,700,000
Other Variable Operating Cost	**$/yr**	32,600,000	13,200,000	70,100,000	21,800,000	216,875,209
Coproducts Sales Revenue	**$/yr**	-	-	0	0	18,600,000
Power Sales Revenue	**$/yr**	0	-	5,370,000	5,115,500	3,100,000
Feedstock Throughput Capacity	**tons/day**	2,205	2,205	2,205	2,205	1,339
Product Yield Breakdown						
Gasoline Blendstock	**Gal / Ton**	39.9	64.9	15.85		36.40
Jet Fuel Blendstock	**Gal / Ton**					
Diesel Blendstock	**Gal / Ton**	43.7		61.84	43.3	104.7

TEA = Techno-Economic Analysis

Preliminary. For use by CARB.

Cellulose to Ethanol Techno-economic Assumptions

		Cellulose to Ethanol	
TEA Component	**Units**	Biochem* (Humbird et al. 2011)	Thermochem* (Dutta et al. 2011)
Minimum Fuel Selling Price	**$/gal**	2.75	2.6
Process Yield	**gal/ton**		
Fixed Capital Investment	**$**	447,000,000	545,115,008
Fixed Operating Cost	**$/yr**	11,800,000	25,703,000
Other Variable Operating Cost	**$/yr**	30,700,000	8,956,000
Coproducts Sales Revenue	**$/yr**	0	14,417,000
Power Sales Revenue	**$/yr**	6,200,000	-
Feedstock Throughput Capacity	**tons/day**	2,205	2,205
Product Yield Breakdown			
Gasoline Blendstock	**Gal / Ton**	79.00	83.80
Jet Fuel Blendstock	**Gal / Ton**		
Diesel Blendstock	**Gal / Ton**		

*Techno-economic assumptions were aligned with more recent unpublished design cases.

TEA = Techno-Economic Analysis

Preliminary. For use by CARB.

Carbon Intensity Assumptions by Pathway

Pathway	Technology	CARB-specified Carbon Intensity ($g\ CO_2e/MJ$)		
		Jet	Diesel	Gasoline
Algae to Hydrocarbons		76.4	63.3	
Cellulose to Ethanol	Biochemical			14.4
Cellulose to Ethanol	Thermochemical			15.6
Cellulose to Hydrocarbons	Catalytic Upgrading of Sugars	25.5		
Cellulose to Hydrocarbons	Cellulosic Ethanol-based Alcohol to Jet	32.4		
Cellulose to Hydrocarbons	Fermentation	37		
Cellulose to Hydrocarbons	Fast Pyrolysis	16.6	15.4	15.4
Cellulose to Hydrocarbons	Fischer Tropsch	13.7	14.4	14.4
Cellulose to Hydrocarbons	Methanol to Gasoline			15.6
Oil Crop to Hydrocarbons	HEFA	59.2	49.2	
Petroleum		93.3	102	99.8
Starch Ethanol				75
Starch Ethanol-based Alcohol to Jet		85.9		

These assumptions, along with the techno-economic analysis assumptions, are used to calculate the value of the Low Carbon Fuel Standard to each pathway.

CARB = California Air Resources Board
CO_2e = carbon dioxide equivalent
MJ = megajoule
HEFA = Hydro-processed Esters and Fatty Acids

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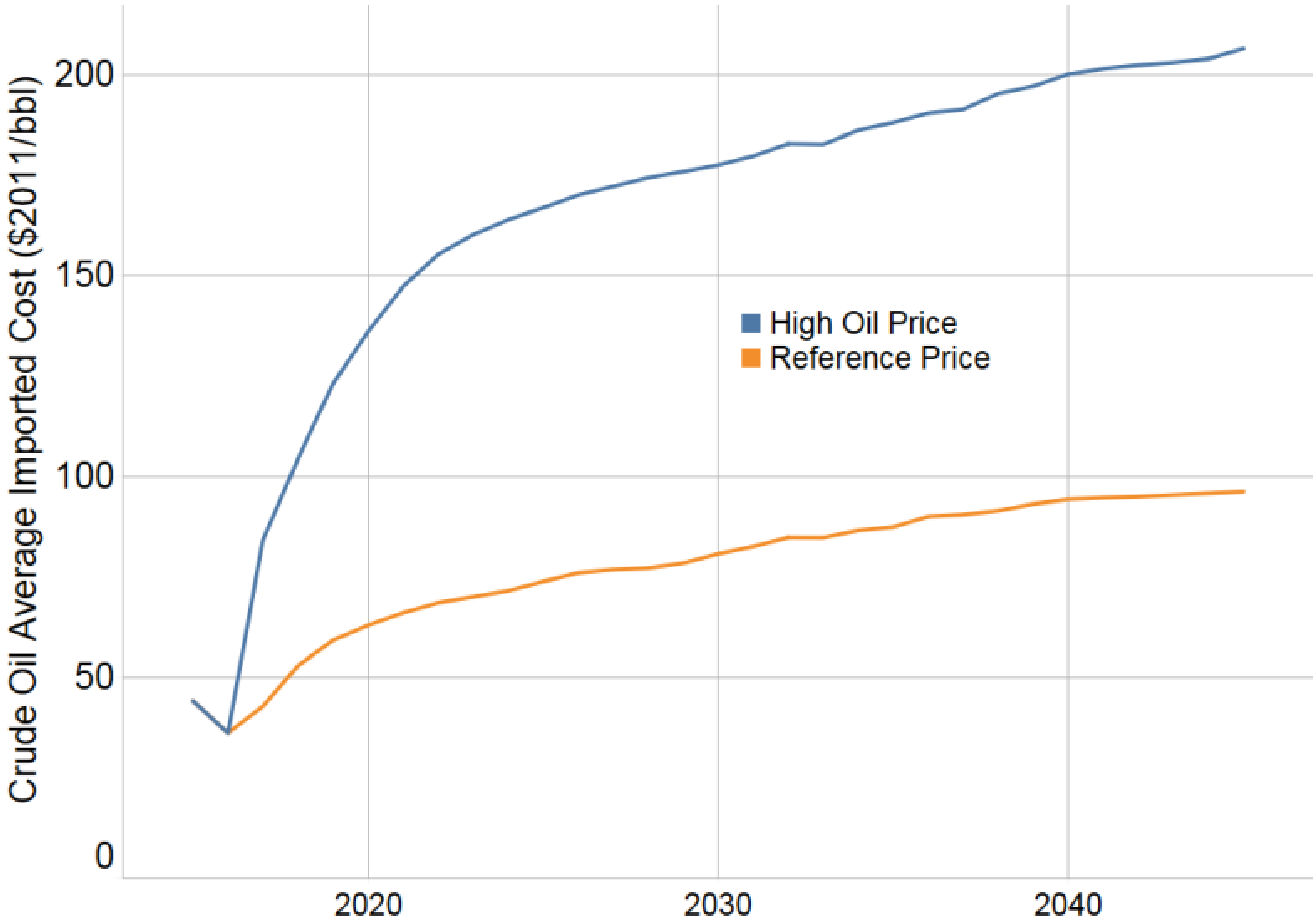
Annual Energy Outlook (AEO 2017) Petroleum Cost



bbl = barrel

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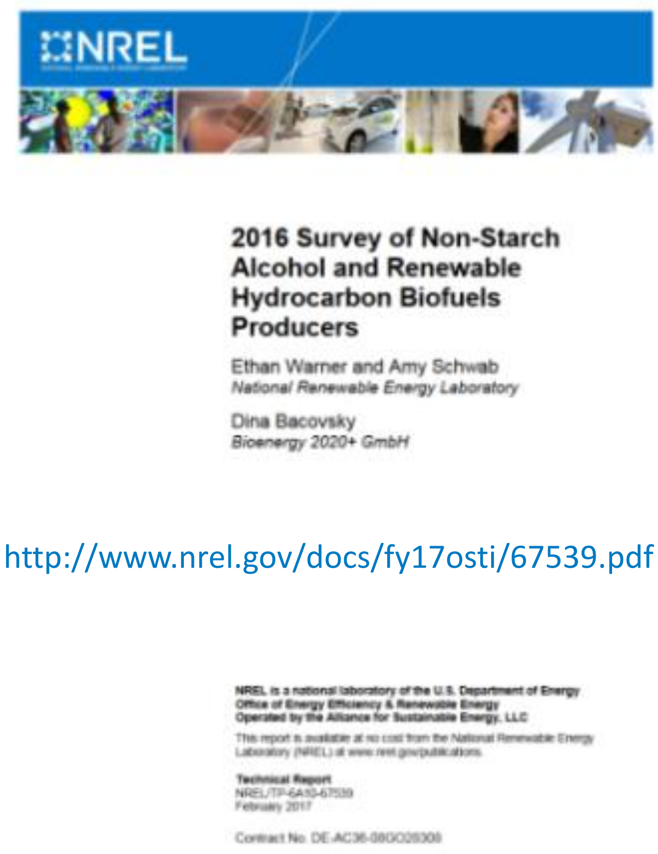
Certain Biorefineries Are Entered in the Biomass Scenario Model (from NREL Survey)

- Biorefineries that are entered in the Biomass Scenario Model advance industrial learning in the model
- Biorefineries that are…
  - Under Construction and Operating
  - In the United States

  ….are entered in the model
- Quantities are based on 2016 NREL Survey
- Consistent with Environmental Protection Agency (U.S. EPA) data
- Includes cellulosic and oil feedstocks
- Does not include biorefineries in planning, idle, or that use Corn Kernel Cellulose
- Next two slides show selected biorefineries



NREL

2016 Survey of Non-Starch Alcohol and Renewable Hydrocarbon Biofuels Producers

Ethan Warner and Amy Schwab
National Renewable Energy Laboratory

Dina Bacovsky
Bioenergy 2020+ GmbH

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

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Technical Report
NREL/TP-6A10-67539
February 2017

Contract No. DE-AC36-08GO28308

http://www.nrel.gov/docs/fy17osti/67539.pdf

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Cellulose to Ethanol Facilities in the U.S., Not Corn Kernel, and Operating or Under Construction are in the Biomass Scenario Model (see overview of biorefineries entered in the model on slide 20)

	Deconstruction Technology	Upgrading Technology	Project Name	Location Detail	Anticipate Product/ Market	Commercial Capacity (MMGY)	Operating	Under Construction	~~Planning~~	~~Idle~~
U.S. Commercial		-	Sweetwater Energy	Mountain Iron, MN, USA	TBS/bioproducts	3.5			▽	
				Rochester, NY, USA	TBS/bioproducts	3.5			▽	
	A/E Pretreatment	Fermentation	DuPont	Nevada, IA, USA	TBS	30	✱ Yes			
			Pacific Ethanol (EdeniQ)	Stockton, CA, USA	TBS	1.5	◁ X			
			POET-DSM	Emmetsburg, IA, USA	TBS	20	✱ Yes			
			Quad County Corn	Galva, IA, USA	TBS	2.1	◁ X			
			Redfield Energy (ICM)	Redfield, SD, USA	TBS	3.42	◁ X			
			Flint Hills (EdeniQ)	Shell Rock, IA, USA	TBS	3	◁ X			
				Fairbank, IA, USA	TBS	3		◁ X		
				Iowa Falls, IA, USA	TBS	2.5		◁ X		
				Menlo, IA, USA	TBS	3		◁ X		
			E Energy Adams (ICM)	Adams, NE, USA	TBS	3		◁ X		
			Fiberight	Hampden, ME, USA	TBS	6		◇ Yes		
			Kansas Ethanol (ICM)	Lyons, KS, USA	-	3.6		◁ X		
			MAAPW (EdeniQ)	Madrid, NE, USA	TBS	1.1		◁ X		
			Siouxland Energy (EdeniQ)	Sioux Center, IA, USA	TBS	1.5		◁ X		
			Beta Renewables	Clinton, NC, USA	TBS	20			▷	
			ZeaChem	Boardman, OR, USA	TBS/bioproducts	22			▽	
			Abengoa	Hugoton, KS, USA	TBS	25				✱
	Gasification	Syngas Catalytic	Enerkem	Pontotoc, MS, USA	TBS/bioproducts	10			◇	
		Fermentation	INEOS New Planet Bioenergy	Vero Beach, FL, USA	TBS	8				◇
International Commercial	A/E Pretreatment	Fermentation	GranBio	Sao Miguel, Brazil	TBS	22	✱			
			Raizen Energia	Piracicaba, Brazil	TBS	11	✱			
			ShanDong Longlive	Yucheng, China	TBS	16	✱			
			Henan Tianguan Group	Nanyang, China	TBS	14	✱			
						72			✱	
				Zhenping, China	TBS	4.8	✱			
			IGPC Ethanol	Alymer, Canada	-	3.18		◁		
			Beta Renewables	Crescentino, Italy	TBS	20	✱			
				Fujian, China	TBS	20			✱	
				Strazske, Slovakia	TBS	20			✱	
			COFCO Zhaodong Co.	Zhaodong, China	TBS	24			▷	
	Gasification	Syngas Catalytic	Enerkem	Edmonton, Canada	TBS/bioproducts	10	◇			
				Varennes, Canada	TBS/bioproducts	10			◇	

Intermediate Product
- Sugars
- Syngas

Feedstock Category
- ◁ ~~Corn Kernel Cellulose~~
- ✱ Crop Residues
- ▷ Dedicated Energy Crops
- ◇ MSW
- ▽ Woody Biomass

Items circled and not marked X or struck out are entered in the model.

Hydrocarbon-producing Facilities in the U.S. and Operating or Under Construction are in the Biomass Scenario Model (see overview of biorefineries entered in the model on slide 20)

	Deconstruction Technology	Upgrading Technology	Project Name	Location Detail	Anticipate Product/Market	Commercial Capacity (MMGY)	Operating	Under Construction	~~Planning~~	~~Idle~~
U.S. Commercial	-	Oil Catalytic	AltAir Fuels	Los Angeles, CA, USA	TBS	42	△			
			Cetane Energy	Carlsbad, NM, USA	TBS	3	△			
			Renewable Energy Group	Geismar, LA, USA	TBS	75	△			
			Diamond Green Diesel	Norco, LA, USA	TBS	160	△			
						115		△		
			East Kansas Agri-Energy	Garnett, KS, USA	TBS	3		△		
			Emerald Biofuels	Plaquemine, LA, USA	TBS	88			△	
			SG Preston	South Point, OH, USA	TBS	120			△	
			Green Energy Products	Wichita, KS, USA	TBS	3				△
	Gasification	Syngas Catalytic	Fulcrum BioEnergy	Reno, NV, USA	TBS	10			◇	
			Red Rock Biofuels	Lakeview, OR, USA	TBS	15.5			▽	
			Sundrop Fuels	Boyce, LA, USA	TBS	200			▽	
	Pyrolysis	-	Ensyn	Vienna, Georgia, USA	refinery feedstock	20			▽	
		Oil Catalytic	KiOR	Columbus, MS, USA	TBS	13				▽
International Commercial	-	-	Solazyme	Moema, Brazil	TBS/bioproducts	2.7	○			
		Oil Catalytic	ENI	Port Marghera, Italy	TBS	24	△			
			Neste Oil	Porvoo, Finland	TBS	63	△			
				Rotterdam, Netherlands	TBS	275	△			
				Singapore, Singapore	TBS	275	△			
			UPM Biofuels	Lappeenranta, Finland	TBS	32	△			
			La Mède	Châteauneuf-les-Martig..	TBS	24		△		
	Gasification	Syngas Catalytic	Total	Dunkirk, France	TBS	72		▽		
	Pyrolysis	-	BTG	Hengelo, Netherlands	refinery feedstock	5.3	▽			
			Fortum	Joensuu, Finland	heating oil	24	▽			
			Ensyn	Renfrew, Canada	heating oil	3	▽			
				Cote Nord, Canada	refinery feedstock	10		▽		
				Aracruz, Brazil	refinery feedstock	20			▽	

Intermediate Product
- Oils
- Pyrolysis Oils
- Syngas

Feedstock Category
- ○ Algae
- △ FOG
- ◇ MSW
- ▽ Woody Biomass

Items circled and not struck out are entered in the model.

Assumptions about Integrated Biorefineries Producing Jet Fuel, Including Offtakes

Offtake start date variations include: 2018 and 2021, shown here for 2018.

Company Name	Location	Type	Jet Share (%)	Assumed Capacity [GPY]	Offtake Airline	Modeled Construction Start	Modeled Offtake Start	Modeled Offtake End	CARB category
AltAir Fuels	Los Angeles, CA	HEFA	15.7	42,000,000		2013			Merchant
Cetane Energy	Carlsbad, NM	HEFA	15.7	3,000,000		2011			Merchant
Diamond Green Diesel	Norco, LA	HEFA	15.7	160,000,000		2011			Merchant
Diamond Green Diesel	Norco, LA	HEFA	15.7	115,000,000		2015			Merchant
East Kansas Agri-Energy	Garnett, KS	HEFA	15.7	3,000,000		2012			Merchant
Renewable Energy Group	Geismar, LA	HEFA	15.7	75,000,000		2013			Merchant
AltAir Fuels	CA	HEFA	15.7	5,000,000	United		2016	2018	Offtake
Fulcrum Bioenergy	NV	FT	32.4	37,500,000	Cathay Pacific		2018	2027	Additional Offtake
Fulcrum Bioenergy	NV	FT	32.4	9,000,000	United		2018	2027	Additional Offtake
Red Rock Biofuels	OR	FT	32.4	3,000,000	Southwest		2018	2024	Additional Offtake
Red Rock Biofuels	OR	FT	32.4	3,000,000	FedEX		2018	2024	Additional Offtake
D'Arcinoff Group	TX	FT	32.4	500,000	GE		2018	2022	Additional Offtake
SG Preston	OH	HEFA	15.7	10,000,000	jetBlue		2018	2027	Additional Offtake
Gevo	MN	ATJ	84.1	8,000,000	Lufthansa		2018	2022	Additional Offtake

Integrated Biorefineries that have offtakes and are not yet operating or under construction (Warner et al. [2017]) are assumed to start offtakes in 2018. Capacities and durations from:

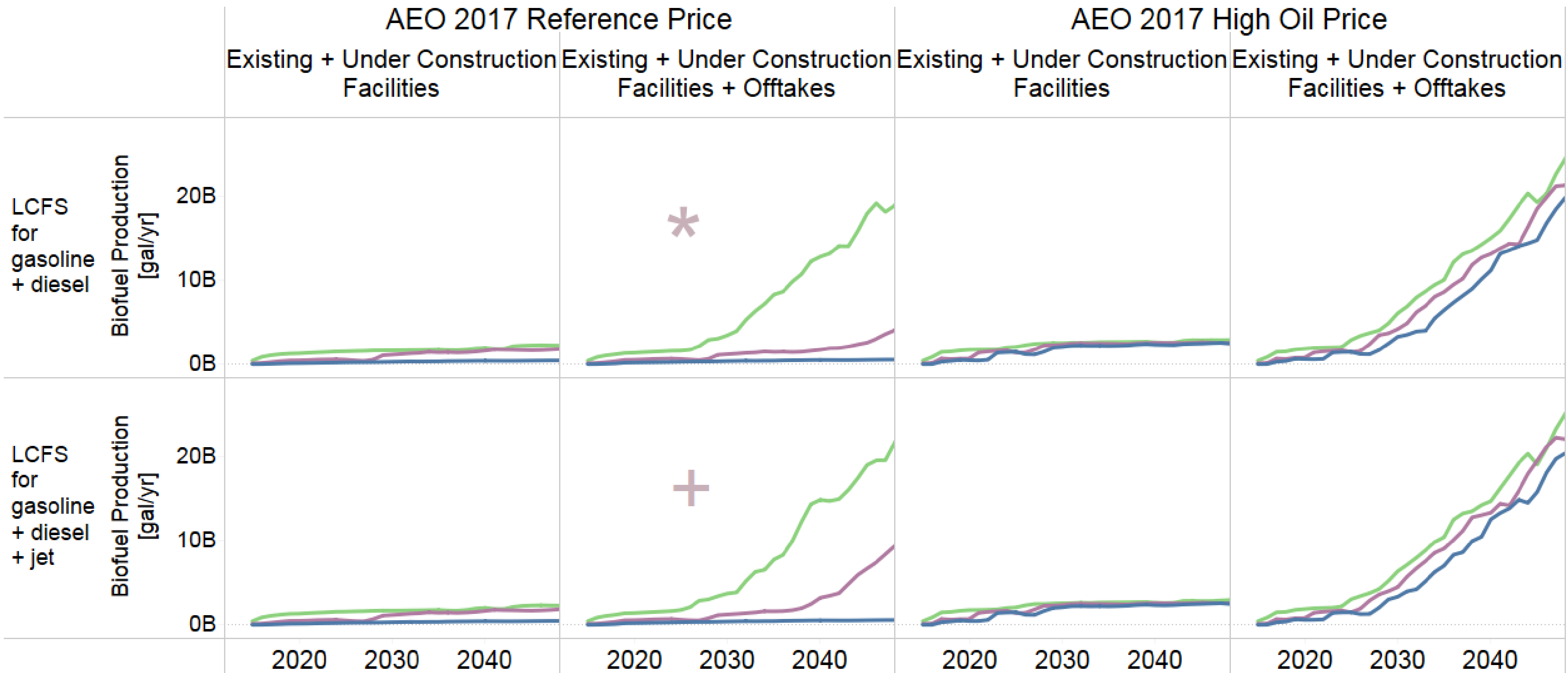
http://www.bizjournals.com/denver/blog/earth_to_power/2014/09/red-rock-biofuels-lands-contracts-with-southwest.html
http://dgenergy.darcinoff.com/projects/hudspeth-county-texas
http://www.biofuelsdigest.com/bdigest/2016/09/19/jetblue-makes-record-setting-330-million-gallon-renewable-jet-fuel-order/
http://www.biofuelsdigest.com/bdigest/2016/09/08/gevo-lufthansa-rock-markets-with-renewable-jet-fuel-deal/
http://fulcrum-bioenergy.com/wp-content/uploads/2015/03/2015-06-30-Fulcrum-United-Strategic-Partnership-FINAL.pdf

HEFA = Hydro-processed Esters and Fatty Acids: FT = Fischer Tropsch; ATJ = Alcohol to Jet

Preliminary. For use by CARB.

Results

Biofuel Production with Different Petroleum Prices, Offtake Agreements, LCFS coverage, and RIN Values



- D6 RIN = $0
- D6 RIN = $0.70
- D6 RIN = $1.70

LCFS Credit Value = $90

* and + indicate conditions selected for detailed views

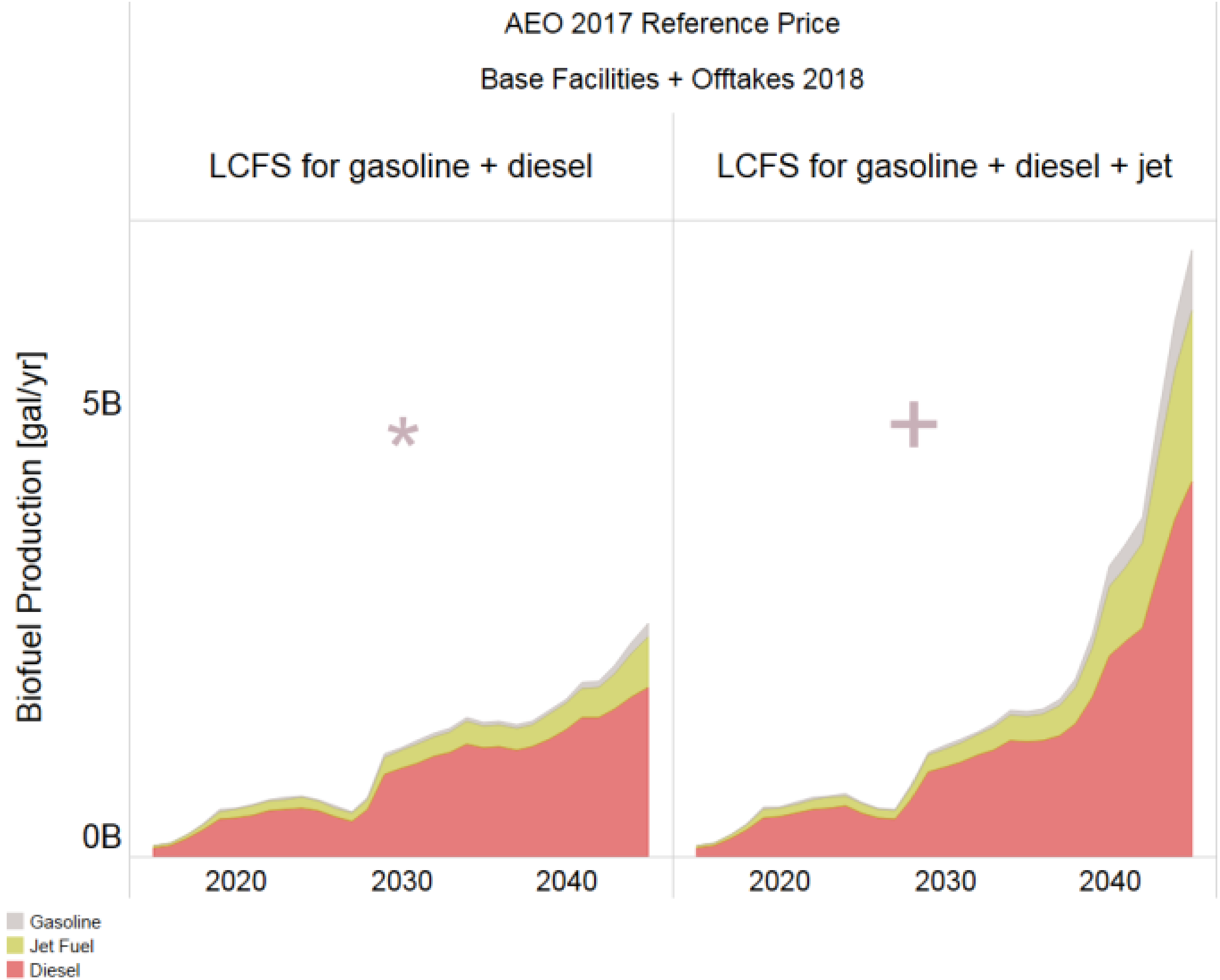
AEO = Annual Energy Outlook

LCFS = Low Carbon Fuel Standard

RIN = Renewable Identification Number

Preliminary. For use by CARB.

Product Mix: * and + from slide 25

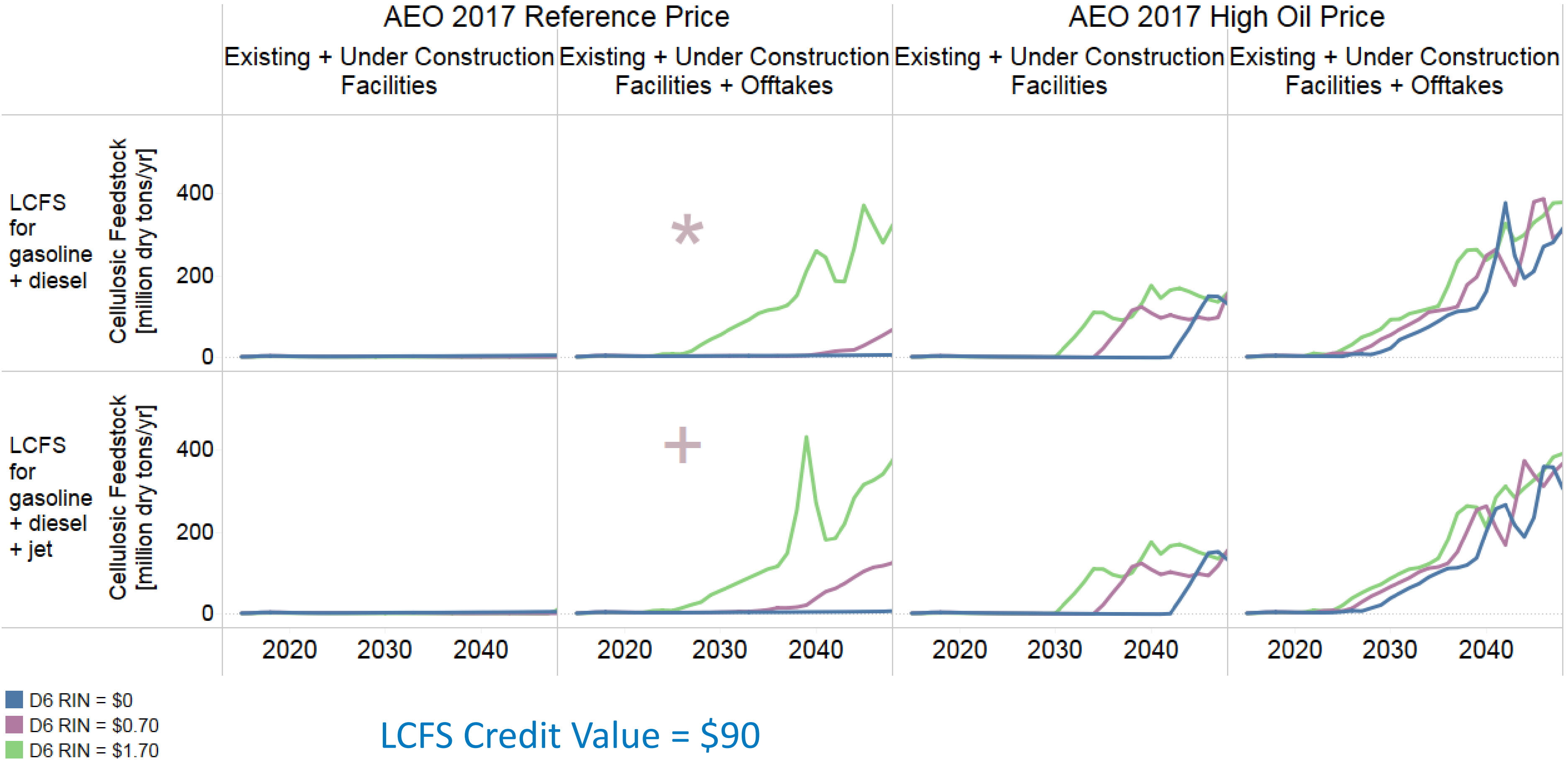


D6 RIN = $0.70
LCFS Credit Value = $ 90

AEO = Annual Energy Outlook
LCFS = Low Carbon Fuel Standard

Preliminary. For use by CARB.

Cellulosic Feedstock Supply: * and + from slide 25



LCFS Credit Value = $90

* and + indicate conditions selected for detailed views

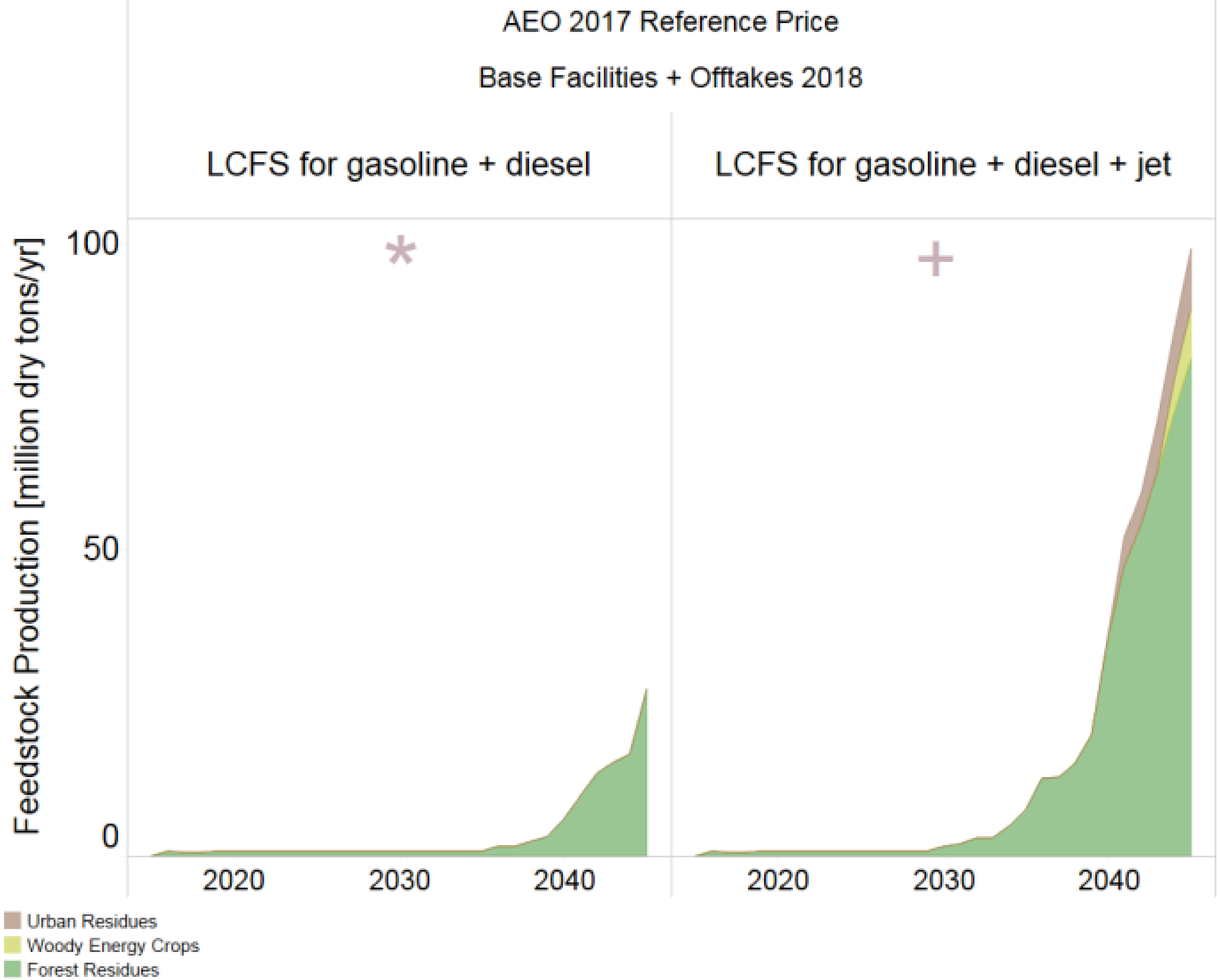
AEO = Annual Energy Outlook

LCFS = Low Carbon Fuel Standard

RIN = Renewable Identification Number

Preliminary. For use by CARB.

Woody Feedstock Supply: * and + from slide 25



D6 RIN = $0.70

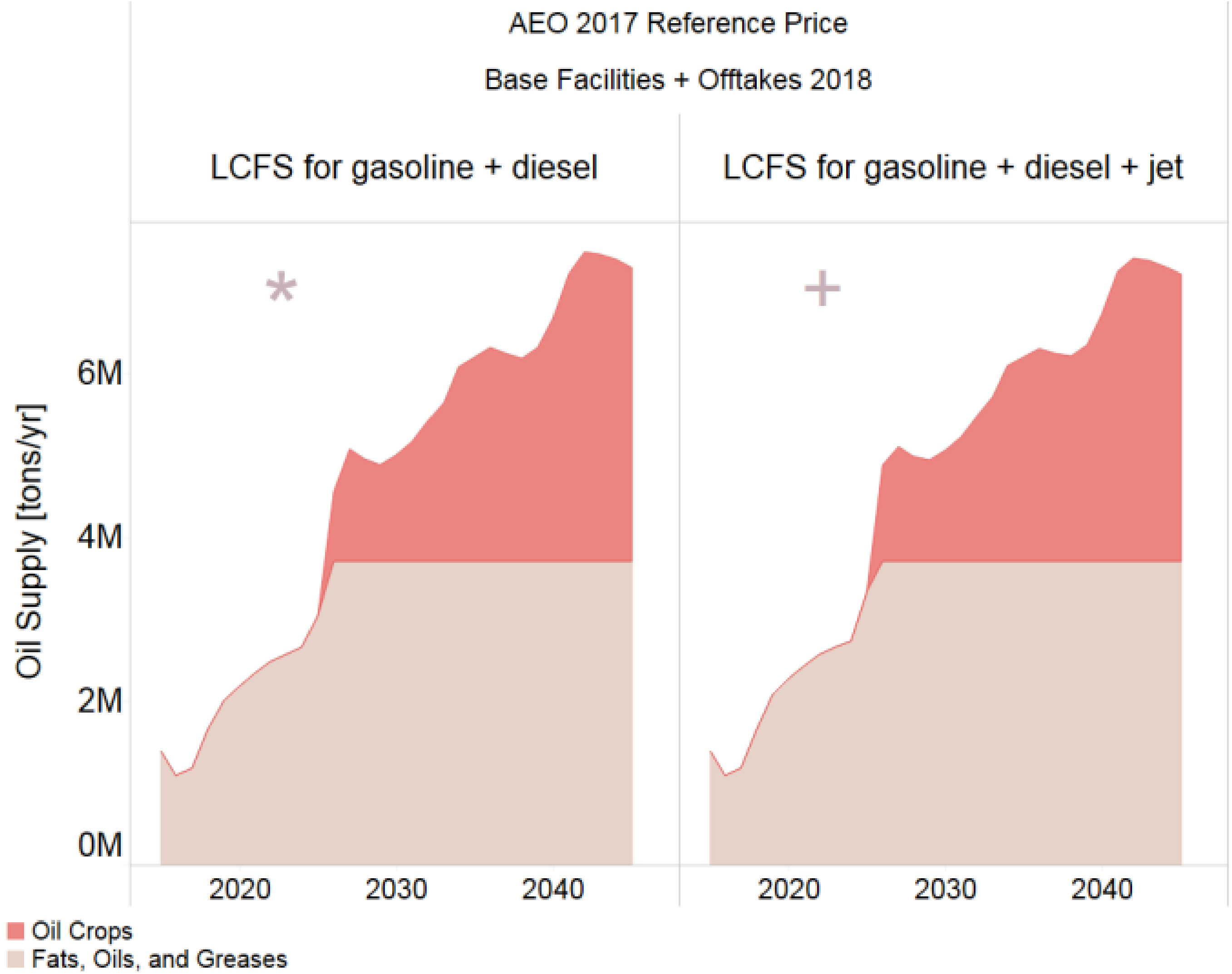
LCFS Credit Value = $ 90

AEO = Annual Energy Outlook

LCFS = Low Carbon Fuel Standard

Preliminary. For use by CARB.

Oil Feedstock Supply: * and + from slide 25



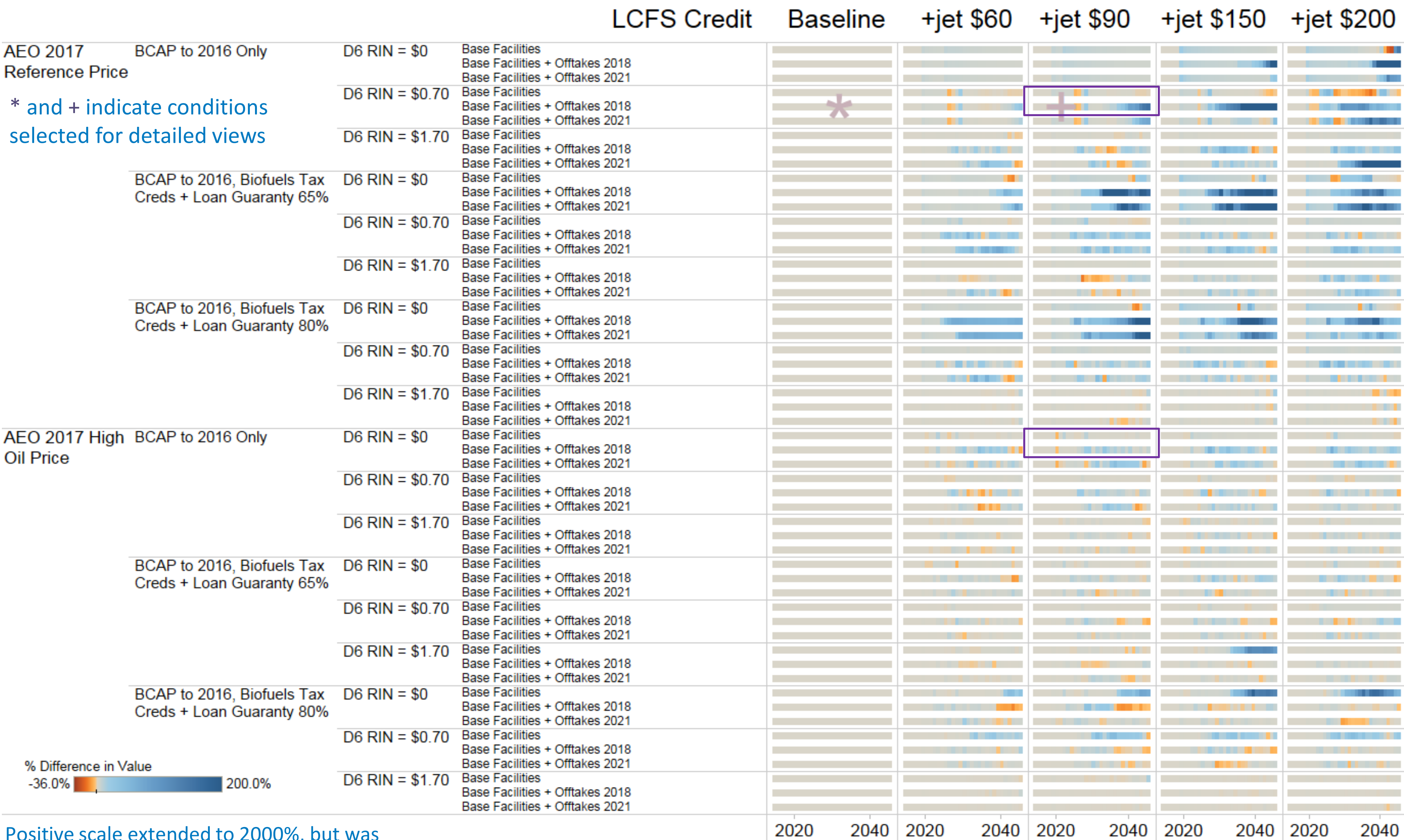
D6 RIN = $0.70
LCFS Credit Value = $ 90

AEO = Annual Energy Outlook
LCFS = Low Carbon Fuel Standard

Preliminary. For use by CARB.

Jet LCFS Increases Biofuel Production Under Certain Conditions

Baseline = gas and diesel only (LCFS = $60, $90, $150, or $200)



* and + indicate conditions selected for detailed views

Positive scale extended to 2000%, but was truncated for clarity.

* , + , and ▭ indicate selections for detailed views

Preliminary. For use by CARB.

Conclusions and Limitations

Jet Low Carbon Fuel Standard Could Increase Production of Hydrocarbons from Biomass

- Under many of the conditions that we modeled, extending the LCFS to include alternative jet fuel increases production of hydrocarbons from cellulose and oil crops.
- Within the range of incentives and economic conditions that we examined, increased production appears more likely to increase production of hydrocarbons when other incentives and economic conditions for biofuels are moderately favorable, rather than when they are extremely favorable or extremely unfavorable.
- Under some conditions, extending the LCFS to jet fuel decreases production of hydrocarbons in some years, due to the dynamic market response to higher demand for cellulosic feedstocks from both hydrocarbon and ethanol pathways.
- The increases in annual biofuels production that occurred with the extension of the LCFS to jet were orders of magnitude greater, and occurred during more of the analysis conditions, than the decreases.

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Limitations

- Results depend upon many assumptions
  - Input assumptions may not reflect future conditions
  - Model algorithms are necessarily a simplified representation of reality
- Not all relevant alternative jet fuel or other pathways are represented
- The simplified representation of LCFS credit applies to the Pacific region, one of the 10 regions in the Biomass Scenario Model
- Price feedback is not included in LCFS credit markets, RIN markets, or representation of offtake agreements.
- Offtakes are modeled as fixed scenarios of **guaranteed** production, strongly driving industrial learning
- Results show system behaviors are more robust than specific quantitative results.

Preliminary. For use by CARB.

Discussion

References

References

- **References for Techno-Economic Assumptions**

  - Davis, R.; Tao, L.; Tan, E. C. D.; Biddy, M. J.; Beckham, G. T.; Scarlata, C.; Jacobson, J.; Cafferty, K.; Ross, J.; Lukas, J.; Knorr, D.; Schoen, P. (2013). Process Design and Economics for the Conversion of Lignocellulosic Biomass to Hydrocarbons: Dilute-Acid and Enzymatic Deconstruction of Biomass to Sugars and Biological Conversion of Sugars to Hydrocarbons. NREL/TP-5100-60223. Golden, CO: National Renewable Energy Laboratory. Available from: http://www.nrel.gov/docs/fy14osti/60223.pdf.
  - Davis, R., L. Tao, C. Scarlata, E.C.D. Tan, J. Ross, J. Lukas, and D. Sexton. 2015. Process Design and Economics for the Conversion of Lignocellulosic Biomass to Hydrocarbons: Dilute-Acid and Enzymatic Deconstruction of Biomass to Sugars and Catalytic Conversion of Sugars to Hydrocarbons. NREL/TP-5100-62498. Golden, CO: NREL. http://www.nrel.gov/docs/fy15osti/62498.pdf.
  - Dutta, A.; Talmadge, M.; Hensley, J.; Worley, M.; Dudgeon. D.; Barton, D.; Groenendijk, P.; Ferrari, D.; Stears, B.; Searcy, E.M.; Wright, C.T.; Hess, J.R. (2011). *Process Design and Economics for Conversion of Lignocellulosic Biomass to Ethanol Thermochemical Pathway by Indirect Gasification and Mixed Alcohol Synthesis.* NREL/TP-5100-51400. Golden, CO: National Renewable Energy Laboratory. Accessed May 12, 2014: http://www.nrel.gov/biomass/pdfs/51400.pdf.
  - Jones, S.B., P.A. Meyer, L.J. Snowden-Swan, A.B. Padmaperuma, E. Tan, A. Dutta, J. Jacobson, and K. Cafferty. 2013. Process Design and Economics for the Conversion of Lignocellulosic Biomass to Hydrocarbon Fuels: Fast Pyrolysis and Hydrotreating Bio-Oil Pathway. PNNL-23053; NREL/TP-5100-61178. Pacific Northwest National Laboratory, NREL. http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-23053.pdf.
  - Humbird, D.; Davis, R.; Tao, L.; Kinchin, C.; Hsu, D.; Aden, A.; Schoen, P.; Lukas, J.; Olthof, B.; Worley, M.; Sexton, D.; Dudgeon, D. (2011). Process Design and Economics for Biochemical Conversion of Lignocellulosic Biomass to Ethanol Dilute-Acid Pretreatment and Enzymatic Hydrolysis of Corn Stover. NREL/TP-5100-47764. Golden, CO: National Renewable Energy Laboratory. Accessed May 12, 2014: http://www.nrel.gov/biomass/pdfs/47764.pdf.
  - Pearlson, M., Wollersheim, C., Hileman, J. "A techno-economic review of hydroprocessed renewable esters and fatty acids for jet fuel production." *Biofuels, Bioproducts and Biorefining* 7 (2013). DOI: 10.1002/bbb.1378.
  - Staples, M.D., Malina, R., Olcay, H., Pearlson, M.N., Hileman, J.I., Boies, A., Barrett, S.R.H. "Lifecycle greenhouse gas footprint and minimum selling price of renewable diesel and jet fuel from fermentation and advanced fermentation production technologies." *Energy Environmental Science* 7 (2014). DOI: 10.1039/C3EE43655A.
  - Tan, E.C.D., Snowden-Swan, L.J., Talmadge, M., Dutta, A., Jones, S., Ramasamy, K.K., Gray, M., Dagle, R. Padmaperuma, A., Gerber, M., Sahir, A.H., Tao, L., Zhang, Y. "Comparative Techno-Economic Analysis and Process Design for Indirect Liquefaction Pathways to Distillate-Range Fuels via Biomass-Derived Oxygenated Intermediates Upgrading." *Biofuels, Bioproducts and Biorefining* 11 (2016). DOI:10.1002/bbb.1710.
  - Tan, E.C.D., Talmadge, M., Dutta, A., Hensley, J., Schaidle, J., Biddy, M., Humbird, D., Snowden-Swan, L.J., Ross, J., Sexton, D., Yap, R., Lukas, J. "Process Design and Economics for the Conversion of Lignocellulosic Biomass to Hydrocarbons via Indirect LiquefactionComparative Techno-Economic Analysis and Process Design for Indirect Liquefaction." NREL/TP-5100-62402. Golden, CO: NREL. http://www.nrel.gov/docs/fy15osti/62402.pdf.
  - Tao and Aden (2011)

- **Integrated Biorefinery Survey**

  - Warner, E., Schwab, A., Bacovsky, D. "2016 Survey of Non-Starch Alcohol and Renewable Hydrocarbon Biofuels Producers." Golden, CO: National Renewable Energy Laboratory (2017). NREL/TP-6A10-67539.

- **Websites for Offtake Agreements**

  - http://www.bizjournals.com/denver/blog/earth_to_power/2014/09/red-rock-biofuels-lands-contracts-with-southwest.html
  - http://dgenergy.darcinoff.com/projects/hudspeth-county-texas
  - http://www.biofuelsdigest.com/bdigest/2016/09/19/jetblue-makes-record-setting-330-million-gallon-renewable-jet-fuel-order/
  - http://www.biofuelsdigest.com/bdigest/2016/09/08/gevo-lufthansa-rock-markets-with-renewable-jet-fuel-deal/
  - http://fulcrum-bioenergy.com/wp-content/uploads/2015/03/2015-06-30-Fulcrum-United-Strategic-Partnership-FINAL.pdf

- **References for Carbon Intensities**

  - California Air Resources Board, personal communication with James Duffy.

Preliminary. For use by CARB.

Major Biomass Scenario Model Publications (2013-2015)

Biomass Scenario Model Documentation

- Peterson, S., E. Newes, D. Inman, L. Vimmerstedt, D. Hsu, C. Peck, D. Stright, and B. Bush. “An Overview of the Biomass Scenario Model.” In The 31st International Conference of the System Dynamics Society. Cambridge, MA, 2013. http://www.systemdynamics.org/conferences/2013/proceed/papers/P1352.pdf.

Journal Articles

- Clark, C., Y. Lin, B. Bierwagen, L. Eaton, M. Langholtz, P. Morefield, C. Ridley, L. Vimmerstedt, S. Peterson, and B. Bush. “Growing a Sustainable Biofuels Industry: Economics, Environmental Considerations, and the Role of the Conservation Reserve Program.” *Environmental Research Letters* 8, no. 2 (June 1, 2013): 025016. doi:10.1088/1748-9326/8/2/025016.
- Newes, E., B. Bush, C. Peck, and S. Peterson. “Potential Leverage Points for Development of the Cellulosic Ethanol Industry Supply Chain.” *Biofuels* 6, no. 1–2 (March 4, 2015): 21–29. doi:10.1080/17597269.2015.1039452.
- Vimmerstedt, L., B. Bush, and S. Peterson. “Ethanol Distribution, Dispensing, and Use: Analysis of a Portion of the Biomass-to-Biofuels Supply Chain Using System Dynamics.” *PLoS ONE* 7, no. 5 (May 14, 2012): e35082. doi:10.1371/journal.pone.0035082.
- Vimmerstedt, L., B. Bush, D. Hsu, D. Inman, and S. Peterson. “Maturation of Biomass-to-Biofuels Conversion Technology Pathways for Rapid Expansion of Biofuels Production: A System Dynamics Perspective.” *Biofuels, Bioproducts and Biorefining* 9, no. 2 (March 1, 2015): 158–76. doi:10.1002/bbb.1515.

Technical Reports

- Inman, D., L. Vimmerstedt, E. Newes, B. Bush, and S. Peterson. “Biomass Scenario Model Scenario Library: Definitions, Construction, and Description.” Technical Report. Golden, CO: National Renewable Energy Laboratory, April 2014. http://dx.doi.org/10.2172/1129277.
- Johnson, C., E. Newes, A. Brooker, R. McCormick, S. Peterson, P. Leiby, R. Uria Martinez, G. Oladosu, and M. Brown. “High-Octane Mid-Level Ethanol Blend Market Assessment.” Golden, CO: National Renewable Energy Laboratory, December 2015. http://www.nrel.gov/docs/fy16osti/63698.pdf.
- Lin, Y., E. Newes, B. Bush, S. Peterson, and D. Stright. “Biomass Scenario Model Documentation: Data and References.” Technical Report. Golden, CO: National Renewable Energy Laboratory, May 1, 2013. http://www.osti.gov/bridge/servlets/purl/1082565/.
- Vimmerstedt, L., B. Bush, and S. Peterson. “Effects of Deployment Investment on the Growth of the Biofuels Industry.” Technical Report. Golden, CO: National Renewable Energy Laboratory, December 2013. http://dx.doi.org/10.2172/1118095.

Conference Papers

- Vimmerstedt, L., B. Bush, and S. Peterson. “Dynamic Modeling of Learning in Emerging Energy Industries: The Example of Advanced Biofuels in the United States.” In *The 33rd International Conference of the System Dynamics Society*. Cambridge, MA, 2015. http://www.systemdynamics.org/conferences/2015/proceed/papers/P1067.pdf.

Publications List on Zotero: https://www.zotero.org/groups/bsm_publications

Preliminary. For use by CARB.

Thank you!

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