

Policies for California's Energy Future – Scaling Up Advanced Biofuels

Policy Options to Accelerate the Deployment of Low-carbon Transportation Fuels

California Council on Science and Technology

May 2014

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California Council on Science and Technology
May 2014

ACKNOWLEDGMENTS

This report has been prepared for the California Council on Science and Technology (CCST) with funding from the Heising-Simons Foundation. CCST would like to thank the Nathan Cummings Foundation for their support of the reports produced in the Policies for California's Energy Future series. We would also like to thank Lawrence Livermore National Laboratory for underwriting the leadership of this effort.

MESSAGE FROM THE AUTHOR

The authors would like to thank the multitude of people that provided information and thoughtful comments on this paper

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May 2014

ISBN-13: 978-1-930117-85-3

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Table of Contents

Executive Summary	5
Introduction	7
Section 1. Current Status of Advanced Biofuels	9
Section 2. Potential Benefits of In-state Production of Drop-in Advanced Biofuels	11
2.1 Jobs	11
2.2 Increased Tax Revenue	12
2.3 Reduced Waste Disposal in Landfills	13
2.4 Improved Air Quality	13
2.5 In-state Versus Out-of-state Production	14
Section 3. Meeting LCFS	15
Section 4. Four Paths and Their Capital Requirements Based on Company Examples	17
Section 5. Policy Options	19
Promoting In-state Production	20
AB32 and LCFS Policy Changes	21
Price Collar – Minimum and Maximum Prices for LCFS Credits	23
Expansion of Credit Trading Market	24
Appendix A: Biomass Pathway Assessment	25

Executive Summary

This report discusses a set of policy options for the California Low Carbon Fuel Standard (LCFS) and AB32 that could be considered as part of regular program reviews in 2014. Our goal is to increase the flow of capital into the advanced biofuel market and to increase the economic benefits to California.

By 2020, the LCFS is designed to achieve a 10 percent reduction in carbon intensity of California transportation fuels. The standard is technology neutral, encouraging electrification of transportation, the use of natural gas, bio-methane, biodiesel, hydrogen, reduced carbon ethanol, renewable gasoline and renewable diesel. While the state should encourage all solutions, this report focuses on renewable gasoline and diesel. These fuels are important because they are the only fuels that can be used in any quantity in existing vehicles and existing infrastructure and thus have the potential to scale up more rapidly than solutions that require changes to the vehicle (or a new vehicle) or that can be blended only in limited quantity due to current vehicle, infrastructure and regulatory limitations.

Assuming that the renewable gasoline and diesel production scales up by 2020 to compete for half of that year's LCFS production requirement, it would require about 1 billion gallons of low-carbon fuel and private project capital investment of between \$5 and \$20 billion - depending on the technology and process improvements by industry. About one quarter of this capacity already exists. As documented in the authors' 2013 report "E2 Advanced Biofuel Market Report", this technology's 2013 production capacity was 229 million gallons.¹ As discussed in the 2011 CCST report "California's Energy Future"², California needs sources of low-carbon fuel to supply transportation and heat use that cannot be met by other solutions. Reaching 1 billion gallons is a critical milestone to building a market to support California's long-term climate goals. This level of scale would provide the foundation for expansion and cost curve reductions to meet California's 2050 emission targets.

To attract private capital and give investors a clearer sense of the economic returns, this paper looks at three policy changes:

1. Establish a floor on LCFS credits - by having a minimum value for the sale of an LCFS credit, the market would be able to calculate a known minimum return on investment. This concept is similar to the floor price concept on the auction of allowances.
2. Expand the trading market - by expanding the number of participants that can buy/sell LCFS credits the liquidity is enhanced and prices are more stable.
3. Allow obligated parties an "alternative compliance" to purchasing allowances (beginning in 2015) by investing in "qualified" projects that result in the development and use of new transportation fuels and technologies in California. This would be a change to the AB32

¹ <http://www.e2.org/ext/doc/E2AdvancedBiofuelMarketReport2013.pdf> Table 3

² <http://www.ccst.us/publications/2011/2011energy.php>

allowance allocation policy and would apply only to a portion of a obligated party's obligations.

The economic benefits of the LCFS to the California economy can be enhanced in two ways: (1) increase the use of California biomass and the number of conversion facilities built in California and (2) limit any negative effects of LCFS credit pricing. Consequently, we examine two policy changes:

1. Revise policies that discourage appropriate use of biomass as a feedstock for advanced biofuels. This will encourage facilities to be based in California (since the economics require that facilities be located near the source of their feedstock). One example is providing diversion credit for separated municipal solid waste that is appropriately converted to liquid fuel.
2. Establish a ceiling on LCFS credits - a ceiling can be used to cap the maximum impact of the LCFS on the retail price of fuels sold in California. This provides both market stability as well as making the overall program more stable as unexpected swings in supply/demand would not cause large price spikes.

The current market value of an LCFS credit more than covers the cost of transporting fuel to the California LCFS market. While this provides environmental benefits to California and helps grow the industry, the maximum economic benefit to California occurs when more fuel is produced in the state and helps to grow a local biomass industry shifting former waste material into high quality, clean fuel.

To understand the possible development of California biomass-to-renewable gasoline/diesel trend, we look at sources of biomass process approaches that are currently being actively pursued by industry in the U.S. and how those might be replicated in California.

Introduction

Advanced biofuels have the potential to provide California with both cleaner air and economic opportunities, especially when produced within the state. Advanced biofuels are defined to have a minimum of a 50 percent reduction in carbon intensity over gasoline and diesel, so even modest blend levels in our fuel supply could reduce the greenhouse gas emissions of our fuel by up to 10 percent in 2020, and help us meet the Low Carbon Fuel Standard (LCFS) effectively. These fuels also typically burn cleaner, thus reducing criteria pollutants.³ Advanced biofuels can be produced in a variety of urban and rural settings with different feedstocks, providing a distributed economic opportunity across the state.

California and the U.S. have a long history of efforts to reduce the environmental impacts from the transportation sector. Over the next several years, a combination of these efforts and improved technologies will work together to reduce the carbon intensity of transportation fuels with a corresponding drop in fossil fuel usage:

1. Process improvements in ethanol are providing emissions reductions opportunities for California's gasoline engines. However, ethanol in gasoline vehicles is limited because of the blend cap of 10-15 percent or 1.3 -1.9 billion gallons unless there is wider production and use of flex-fuel vehicles and E85 (80% ethanol).
2. Biodiesel in use today includes low carbon options that provide long-term emissions benefits for the diesel fleet. Existing biodiesel production reached over 1 billion gallons in 2013. EPA projections indicate this number will be over 2 billion gallons nationally by 2022.⁴ Biodiesel is limited by most vehicle warranties to 5 percent - 20 percent blends, or 150 - 600 million gallons of biodiesel in California.
3. The integration of alternative vehicles, including electric vehicles, natural gas, flex fuel vehicles, and eventually hydrogen, will play an important part in reducing fossil fuel usage in the transportation sector over the long-term. By 2020, these technologies may contribute 22-42 percent of the emission reductions required to meet the LCFS.⁵ New vehicle purchases and fleet turnover happen at a relatively slow rate, which is a primary limiting factor to meeting impending 2020 goals.
4. Drop-in advanced fuels (renewable gasoline & renewable diesel) can work in existing vehicles at high blend rates and existing infrastructure, thereby replacing petroleum without requiring any change in vehicles or infrastructure. By definition, these fuels reduce carbon emissions by more than 50 percent. For the purposes of this report, we model a target of 1 billion gallons production capacity by 2020, which reflects a scale-up of over four times the 2013 capacity of 229 million gallons.

³ Hill, Jason, National Academy of Sciences, 2006. <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC1544066/>.

National Biodiesel Board, <http://www.biodiesel.org/docs/ffs-basics/emissions-fact-sheet.pdf?sfvrsn=4>

⁴ Kruse, John. "Biodiesel Production Prospects for the Next Decade." IHS Global Insight Report. March 2011.

⁵ ICF International. "California's Low Carbon Fuel Standard: Compliance Outlook for 2010." 2013.

<<http://www.caletc.com/wp-content/downloads/LCFSReportJune.pdf>>

This scope of this report is limited to the last category: drop-in advanced biofuels. All other fuel solutions have lower blend limits, minimal impact on criteria air pollution or require changes to vehicles and fueling infrastructure, which limits the rate at which they can be deployed between now and 2020. With sufficient private capital, advanced biofuel production could scale up to meet a significant portion of the LCFS 2020 target.

The LCFS provides sufficient incentive for advanced biofuels to be brought into California. However, California does not appear to provide sufficient incentives for in-state production, potentially foregoing some of the economic benefits it creates from its fuel policy. We will examine how policies that accelerate the deployment of drop-in biofuels in California can maximize the economic benefits, and minimize economic risks of diversifying our transportation fuels. Section 2 will address the additional economic, clean air and carbon emissions reductions benefits of advanced biofuel.

Section 1. Current Status of Advanced Biofuels

Advanced biofuels are those fuels that have less than half the carbon intensity of fossil fuels and minimize their impact on food production, as defined by the U.S. Environmental Protection Agency. As summarized in Table 1, the dominant fuel is currently biodiesel made from waste animal fat and plant oils, followed by ethanol. The advantage of drop-in fuels, i.e. renewable gasoline and diesel, is that they work in the existing infrastructure and automobile fleet. Biodiesel is differentiated from renewable diesel in its chemical composition, and has different effects on the engine. While both can be derived from fats, oils and greases, renewable diesel is more similar to petroleum-derived diesel. Thus renewable diesel is considered a “drop-in” fuel, as there are fewer limitations.

In a separate report series (E2 Advanced Biofuel Market Report), the authors have surveyed the advanced biofuel market and its growth projections over the past three years. The 2013 report provides detailed information on the status of all advanced biofuels, which is summarized in Table 1. Of all advanced biofuels, the capacity to produce drop-in fuels in the U.S. grew from 88 million gallons (MG) in 2012 to 229 million gallons in 2013. The annual survey counts nine projects scheduled for completion by 2015 that total 528 MG if all projects are completed and running at planned capacity. Very few advanced biofuel projects are planned for California, but it is expected that a fair percentage of the fuel will be imported for use in California due to the LCFS.

The main barriers to project implementation are:

- Access to affordable biomass or feedstock
- Collection and transportation of biomass or early stage processing prior to transportation
- Affordable capital for production facilities
- Market certainty
- Efficiency of the fuel production process

Long-term, the primary barrier is the reliable availability of biomass in sufficient quantity. Policy can help provide the market certainty needed to drive investments into advanced biofuels. Certain policies can ease access to capital or help with permitting, thereby making biofuel production more competitive with petroleum counterparts.

Domestic Advanced Biofuel Capacity 2013-2016										
In millions of gallons/year										
	# Companies		2013 Capacity		2014 Capacity		2015 Capacity		2016 Capacity	
	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH	LOW	HIGH
Biodiesel	116	134	718.0	753.8	747.0	784.4	829.5	871.0	954.0	1,001.7
Drop-ins	16	33	229.0	229.7	320.6	321.4	382.3	528.7	417.3	622.6
Ethanol	26	28	12.1	12.2	118.2	118.3	162.8	224.9	207.8	531.8
Other (DME, Butanol)	1	3	1.6	1.7	1.6	20.0	20.0	60.0	20.0	140.0
TOTAL (volume)	159	198	960.7	997.4	1,187.4	1,244.0	1,394.7	1,684.6	1,599.2	2,296.1
TOTAL (gge)			1,021.8	1,058.3	1,227.7	1,276.9	1,425.2	1,688.9	1,625.6	2,186.5

gge = gallons of gasoline equivalent

Table 1.

Domestic advanced biofuel production capacity, according to E2's 2013 Advanced Biofuel Market report. The number of companies represents how many active companies are scaling the capacities listed. Further detail and explanation can be found in the report, publicly available at <http://www.e2.org/jsp/controller?docId=32263>.

Existing California Conversion Potential in 2020

California already holds a wide variety of feedstocks and biomass that could be used to produce advanced biofuels. Youngs and Somerville explored California's biomass potential in their 2013 paper, "California's Energy Future."⁶ We seek to expand on the discussion of the biomass identified in the Youngs and Somerville paper and explore the state revenue potential and capital costs of converting this biomass to fuel. Although there could be other potential uses of biomass, in this paper we only examine conversion into fuel. If recommended amounts of California's biomass were converted to advanced biofuel, it would produce over 2.1 billion gallons in gasoline equivalents each year.⁷ This would result in at least 22 million metric tons (MMT) of CO₂ reduction. The LCFS requires 17 MMT in 2020. The majority of this biomass, however, decomposes where it was generated, is transported to landfills or is incinerated. Although there are a variety of potential uses for waste biomass including conversion to electricity or composting, this report only explores the value of converting post-recycled biomass to fuel.

⁶ Youngs and Somerville, California's Energy Future. California Council on Science and Technology, 2013. Available at: <https://www.ccst.us/publications/2013/2013biofuels.pdf>

⁷ Parker, Nathan. Presentation to the Energy Commission on 3 June 2013. Slide 3. Web resource, 18 June 2013 at: http://www.energy.ca.gov/2013_energy_policy/documents/2013-06-03_workshop/presentations/Session_1/Parker_IEPR_workshop_June_3_2013.pdf

Section 2. Potential Benefits of In-state Production of Drop-in Advanced Biofuels

2.1 Jobs

Biomass Development: Upcycling of Waste and Residue

The greatest economic opportunities of producing biofuels stem from the feedstock production, collection and pre-processing of biomass. Sustainable feedstocks available in California will be discussed below. Feedstock production and aggregation creates roughly 2-4 times the number of jobs as actual fuel production, or about 370 jobs to service a 50-million gallon/year facility.⁸ Thus, agricultural residues can provide new revenue opportunities for farmers. Woody biomass harvesting and collection could provide additional income for the timber industry.

Figure 1 shows the available biomass resources across the state. California currently offers insufficient policies to make an economic case for converting most of this biomass, although there would be significant employment to gather and bundle this biomass for re-sale.

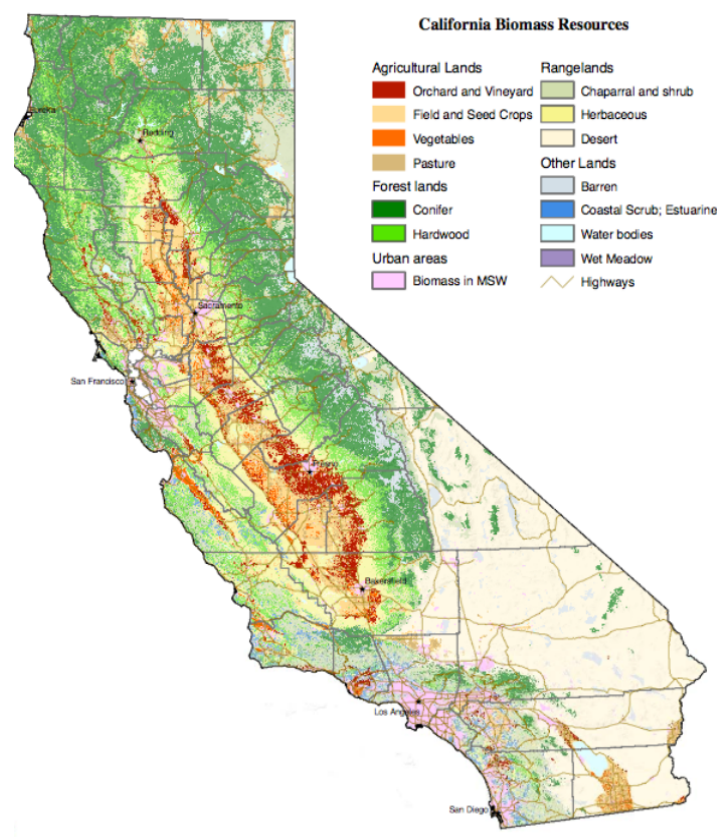


Figure 1.

Map of available biomass resources in California. From Jenkins et al. (2006) *A roadmap for the development of biomass in California*.

⁸ Yudken, Joel. Economic Benefits of Military Biofuels. Commissioned by E2. October 2012. Available at: <http://www.e2.org/ext/doc/HRS-E2MilitaryBiofuelsReportNov2012.pdf>

Biofuel Refining and Production

The in-state economic development opportunities associated with advanced biofuel production are substantial. Advanced biofuels generate approximately 2.4 direct, permanent jobs for every million gallons of installed capacity.⁹ California purchased 12 billion gallons of foreign oil in 2012.¹⁰ An equivalent level of biofuel production in the state could instead directly employ 28,800 people, in addition to keeping our dollars in-state. While producing all 12 billion gallons in-state is not realistic, focusing on the production from the feedstocks shown below in Table 2 would result in over 8,500 jobs.

Biofuel refining and traditional petroleum refining require similar knowledge, infrastructure and skill. California has existing talent pool from its petroleum-refining infrastructure. For example, the Paramount facility in Los Angeles will be re-started by Alt Air to produce renewable jet fuel and diesel for United Airlines.¹¹

2.2 Increased Tax Revenue

Table 2 shows first order, estimated jobs and state tax revenues from the conversion of California biomass to fuels. A full comprehensive review of economic potential would incorporate indirect and induced jobs, economic value added for tax revenue, and other factors. This level of estimation is provided to show a net-positive impact on tax income and employment as a result of biofuel production in the state.

⁹ E2 Advanced Biofuel Market Report 2012, page12.

<http://www.e2.org/ext/doc/E2AdvancedBiofuelMarketReport2012.pdf>

¹⁰ http://energyalmanac.ca.gov/petroleum/statistics/2012_foreign_crude_sources.html

¹¹ <http://www.prnewswire.com/news-releases/united-airlines-and-altair-fuels-to-bring-commercial-scale-cost-competitive-biofuels-to-aviation-industry-210073841.html>

Feedstock	Biomass Potential	Biofuel potential (million gge)	Potential Biofuel Production Jobs	Potential Biomass Production Jobs	Potential Annual Tax Revenue
Animal manure	3.8 MDT	125.0 ^a	311.4	n/a	\$1,050,000
Fats, oils and greases (tons)	0.2 Tons	54.0 ^b	135.0	162	\$1,020,600
Forestry and forest product residue	14.2 MDT	710.0	1,746.6	2076e	\$13,232,625
Agricultural residue (lignocellulosic)	3.5 MDT	175.0	430.5	525	\$3,307,500
Landfill gas	110.0 BCF	474.0 ^c	4,437.0d	n/a	\$15,529,500
Municipal solid waste (Food waste)	1.2 MDT	113.0	274.8	n/a	\$949,200
Municipal solid waste (lignocellulosic)	9.5 MDT	475.0	1,168.5	n/a	\$3,990,000
TOTAL		2,129.0	8,503.8	2,763	\$39.1 M

MDT = million dry tons. BCF = billion cubic feet. gge = gallons of gasoline equivalent.

Table 2.

Of the existing biomass in California, the feedstocks with the greatest potential economic and environmental benefits are agricultural residue, woody biomass and separated municipal solid waste. Each of these feedstock types currently goes to very low-value uses. They have the potential to be converted to liquid fuels.

Sources: Biomass and biofuel potential from [Nathan Parker, UC Davis](#). Job and tax potential calculated by E2 using stated numbers.

2.3 Reduced Waste Disposal in Landfills

Municipalities and residents commonly pay \$50-70/ton to dispose of solid waste. After separating the waste materials for recycling and composting, a portion of the solid waste could be used as feedstock for making liquid fuel. There could be large economic benefits if fuel conversion facilities made high-value fuel from that waste, and reduced the need for landfills. In areas like Los Angeles County, where the Puente Hills landfill closed in 2013, the rising cost of disposing waste calls for alternatives to landfills.

2.4 Improved Air Quality

Replacing fossil fuel production and consumption with advanced biofuels will also provide significant clean air benefits and carbon emissions reductions. Oil refineries contribute to air pollution by emitting NO_x, SO_x and CO₂ among other pollutants. The use of fossil fuels in vehicles adds to this problem, as 75 percent of the pollution in California is due to the use of fossil fuels, and five out of the top ten most polluted cities in the U.S. are in the San Joaquin

Valley.¹² Renewable gasoline and diesel generally produce less emissions leading to cleaner air,¹³ both from refineries and from transportation emissions. In addition, capturing the greenhouse gas emissions from biomass sources (like methane from municipal solid waste) or reducing the incineration of woody biomass can both reduce pollutants and create a new feedstock for energy. Dirty air in California adds up to \$28 billion annually in health and economic costs each year in Los Angeles and the San Joaquin Valley alone.¹⁴

2.5 In-state Versus Out-of-state Production

As Youngs et al. concluded in California's Energy Future, biofuel is emerging as a critical player in meeting California's greenhouse gas reduction goals. There are two choices to meet these goals: import biofuels, or utilize (and increase) in-state biomass. Of the two choices, utilizing our biomass and looking for opportunities to sustainably expand biomass growth provides economic benefits. Otherwise, California will continue to purchase fuel from elsewhere, and forego all of economic opportunities.

Fuel delivered from out of state will have a higher transportation cost than fuels produced in California. We estimate that these additional costs average between \$0.03-0.18/gallon.¹⁵

The LCFS credit value, at \$77/ton in October 2013, provides sufficient value to ship these fuels from out of state. Carbon intensity for shipping fuels is small (2-4 g/MJ)¹⁶, and may be recovered from LCFS credits, which are worth about \$0.35/gallon to the biofuel producer. The primary reason a facility would be built in California would be proximity to a source of biomass. This potential is currently unrealized and the policy changes we suggest in Section 5 could help provide the needed changes.

While California will receive the air quality benefits of using advanced biofuel due to the LCFS, it does not provide sufficient incentives to produce fuel inside the state. Other policy measures must be examined to reap the economic benefits of fuel production inside California.

¹² American Lung Association of California, Air Pollution by the Numbers.

¹³ California Air Resources Board, Alternative Diesel Rulemaking white paper, page 4. Available at: <http://www.arb.ca.gov/fuels/diesel/altdiesel/20130212ADRegConcept.pdf>

¹⁴ California State University Fullerton. The Benefits of Meeting Federal Clean Air Standards in the South Coast and San Joaquin Valley Air Basins. 2008.

¹⁵ Based on transportation costs provided by E2 member Kinhead Reiling

¹⁶ Waugh, Michael. Presentation to California Energy Commission, 10 June 2013.

Section 3. Meeting LCFS

Seventeen MMT of greenhouse gas reductions from transportation fuels are required for the LCFS in 2020.¹⁷ While no one knows the actual mix of solutions that will be used in 2020 - and we want to encourage all alternatives- we model one half, or 8.5 MMT of the total reductions come from drop-in fuels, with the remaining contributions coming from biodiesel, ethanol, electricity, natural gas and other solutions. While the definition of advanced biofuels is a minimum of 50 percent carbon reduction, our analysis of approved and pending pathways for advanced, drop-in biofuels shows carbon intensity values are typically better than a 75 percent reduction, or about 24 g/MJ CO₂ equivalent (CO₂e), vs. 96 g/MJ for gasoline, i.e., 96 grams of CO₂ per mega joule of chemical energy. For comparative purposes, the Air Resources Board (ARB) approved renewable diesel pathway from tallow is 19.65 g/MJ CO₂ equivalent. We are using a 75 percent reduction to be conservative. Given this 75 percent reduction, approximately 925 million gallons could meet the LCFS goals in 2020.¹⁸ If advanced biofuels met one third of the LCFS goals, this would equal 377 million gallons.

Feedstock	Biofuel potential (million gge)	MMTCO ₂ e reductions vs. baseline	Capital expenditures to convert biomass (millions)
Animal manure	125	1.33	\$63.4
Fats, oils and greases	54	0.86	\$231
Forestry and forest product residue	710	9.18	\$7,189
Agricultural residue (lignocellulosic)	175	1.59	\$1,623
Landfill gas	474	4.13	\$706
Municipal solid waste (Food waste)	113	1.03	\$565
Municipal solid waste (lignocellulosic)	475	4.32	\$2,375
TOTAL	2,126	22.29	\$12,752

Table 3.

From the available biomass in California, as much as 22 million metric tons of carbon dioxide equivalent reductions occur if all biomass is converted to fuel. For chosen biofuel pathways, associated capital development totals \$12.7 billion, which is a \$6.00/gallon weighted average capital cost. Biofuel potential comes from California Biomass Collaborative, while the capital costs come from the discussion in the following sections. Emissions reductions were calculated using E2's emissions reductions model, 2013 version.

¹⁷ NRDC fact sheet on LCFS. <http://www.nrdc.org/energy/files/california-petroleum-carbon-reduction-FS.pdf>

¹⁸ E2 Emissions Reductions Model, Cost of Reductions tab.

As a comparison, in July 2013 the technology, policy and management consultancy ICF International assessed potential sources of carbon intensity reductions to meet the LCFS. Given existing project scale-up around the country, ICF found 383 million gallons of renewable diesel and gasoline could come to California in 2020, all of which will likely be produced out-of-state.¹⁹ As discussed above, this is roughly equivalent to one-third of the LCFS targets. However, could California utilize its own in-state biomass and meet as much as one half of the LCFS through advanced, drop-in fuels by 2020? This would require an incremental capacity of 542 million gallons, developed inside California. Nationwide, advanced biofuel projects would represent approximately 1 billion gallons of capacity, a scale from which the industry could begin to realize cost reductions per gallon.

As previously discussed, California has the biomass to fulfill this potential, but there are not enough projects planned in-state to reach this goal. The LCFS is intentionally neutral regarding in-state versus out-of-state production, and other state policies do not encourage locating facilities in California as compared to other states. Therefore most fuels will likely be imported from other states. California will have cleaner air and lower carbon, but may not reap the job and tax rewards for its carbon policy. What more can be done to promote the use of California's biomass for fuel products in state? We examine this question and biomass solutions through the remainder of this paper.

¹⁹ ICF International. "California's Low Carbon Fuel Standard: Compliance Outlook for 2010." 2013. Scenario 2. <<http://www.caletc.com/wp-content/downloads/LCFSReportJune.pdf>>

Section 4. Four Paths and Their Capital Requirements Based on Company Examples

We conducted an analysis of four fuel pathway types, examining in-state biomass availability, carbon reductions, capital costs, operating costs, challenges and opportunities. Complete discussion of these pathways is available in Appendix A. While some financial and carbon intensity data is publicly available, much of it is not.

From our interviews with many of the companies working on production facilities combined with publicly available data and National Renewable Energy Lab (NREL) estimates, we found a large range of capital requirements between \$3.5 and \$20 per gallon of production capacity, but believe \$5 - \$20 per gallon is more likely. Thus for 1 billion gallons of capacity, the private investment is between \$5 and \$20 billion dollars. Already about one quarter of this capacity is built so the incremental private capital is \$3.8 - \$15 billion dollars. All companies describe their fuels as being competitive with fossil fuels (assuming \$100/barrel oil) and some processes look to be very competitive.

In Appendix A we examine drop-in biofuels from the following pathways in greater detail. Here we provide an overview:

- **Waste oils to renewable diesel**
This technology is already at commercial production but is limited by availability of waste oils. Significant amounts of renewable diesel are sold into the California market already.
- **Separated municipal solid waste to fuel**
A portion of the organic waste is suitable for conversion to fuel and is currently going into landfills providing a landfill reduction opportunity. Current state policies limit the potential use of municipal solid waste to fuel.
- **Agricultural and forest residue to fuel**
California has an abundance of this biomass, but aggregation can be cost prohibitive. Some technologies have begun producing fuel from agricultural and forest residue in 2013 and 2014.
- **Biomass to sugars to fuel**
In addition to agricultural residue, purpose grown energy crops could provide new revenue opportunities to rural communities. The high cost of extracting sugar from plant cellulose, the availability of biomass and the development of conversion technologies make this pathway difficult. Regardless, there is potential for this to provide meaningful amounts of fuel to California by 2020.

Section 5. Policy Options

This paper models a target of 1 billion gallons total of low carbon, renewable gasoline and diesel fuel to be delivered to (or produced inside) the state in 2020. This will utilize California biomass resources, produce economic opportunities, and help meet the LCFS. As discussed throughout this paper, California should address policy hurdles for advanced biofuel companies wishing to locate facilities in state in order to receive maximum economic benefit of its policies. Such policies will demonstrate economic benefits without significant economic risks, or costs to end-users. They will also spur economic development, and position the state for further capacity growth to meet 2050 GHG goals.

To attract private capital and give investors a clearer sense of the economic returns, this paper looks at three policy changes:

1. Establish a floor on LCFS credits - by having a minimum value for the sale of an LCFS credit, the market would be able to calculate a known minimum return on investment. This concept is similar to the floor price concept on the auction of allowances.
2. Expand the trading market - by expanding the number of participants that can buy/sell LCFS credits the liquidity is enhanced and prices are more stable.
3. Allow obligated parties an “alternative compliance” to purchasing a portion of their allowances (beginning in 2015) by investing in a state-defined “qualified” project that results in advanced biofuels being produced and sold in California. This would be a change to the AB 32 allowance allocation policy.

To increase the economic value of the LCFS to the California economy, we examine two policy changes:

1. Establish a ceiling on LCFS credits - a ceiling can be used to cap the maximum effect of the LCFS on the retail price of fuels sold in California. This provides both market stability as well as making the overall program more stable as unexpected swings in supply/demand would not cause large price spikes.
2. Revise policies that discourage the proper use of biomass as a feedstock for advanced biofuels. This will encourage facilities to be based in California (since the economics requires that facilities be located near the source of their feedstock). One example is providing diversion credit for separated municipal solid waste that is appropriately converted to liquid fuel.

We explore these proposals in more detail below.

Promoting In-state Production

Permitting

Various permitting processes across state, county and local level agencies create an evident burden for a business wishing to gain permission to build a refinery in California. AB32 related projects should receive high-level assistance to facilitate the numerous permits and waiting periods. California successfully focused on utility-scale renewable electricity with great success. Perhaps a targeted partnership with the Governor's Office of Business and Economic Development (GO-Biz) office for AB32-related requests could streamline the process, guiding potential businesses through the complexities and multiple agency interaction where feasible, while ensuring the highest standards in community and environmental protections are upheld.

Municipal Solid Waste Diversion

For municipal solid waste (MSW) to be appropriately sorted and used for its most optimal pathway, first a series of definitions must be codified so there is clear understanding of the types of biomass and MSW, the legal meaning of "transformation" and the types of conversion technologies. Past legislation categorized many of these too broadly, meaning pyrolysis technologies are treated the same as incineration, and recyclable materials are defined the same as non-recyclable.

Once statute definitions are in place, incentives should be introduced to move biodegradable material away from landfill and instead toward its highest use, which may include composting, recycling and energy conversion. These incentives would best consider lifecycle analysis to identify the optimal ecological pathway for each type of MSW. Any non-landfill use of the waste that can prove a more beneficial ecological use of the material could qualify for permitting or an interim permit that may be extended with air quality testing.

AB32 and LCFS Policy Changes

AB32 and LCFS currently provide California's strongest signals for low carbon fuel infrastructure. What is still lacking is sufficient access to capital to build commercial scale biorefineries. Our analysis identified the following changes to better facilitate the flow of capital from the private sector.

AB32 Alternative Compliance

Beginning in 2015, petroleum refineries must both comply with the LCFS and fuels become subject to the Cap-and-Trade (C&T) program. LCFS compliance is designed to lower the carbon intensity of transportation fuels resulting in 17 MMT CO₂ equivalent emissions in the year 2020. The C&T program is designed to produce additional reductions without regard to the source. Even with full LCFS compliance, regulated parties will nonetheless produce significant CO₂ equivalent emissions and be required to purchase allowances.

We previously identified that if we model renewable gasoline and diesel meeting 50 percent of the 2020 LCFS reductions, it will require a private capital investment of \$3.75 billion to \$15 billion (about one-quarter of the production capacity is already in place). The industry itself is in a good position to select and finance projects but lacks incentive to do so. If sufficient low carbon fuels are not available by 2020, the state will have two bad choices: lower the required reduction or potentially have high credit prices with compliance shortfalls.

One potential solution is an alternative compliance mechanism for regulated parties of fuels under C&T. This mechanism would allow a portion of the allowances to be substituted for a regulated entity investing in a state-approved "qualified project" that produces low-carbon fuel in California for sale in California. Any investment must result in the delivery of fuel that offsets allowance emissions within a specified time period, or the compliance fees will become due to the state. The entity would not receive a dollar for dollar credit but instead there would be some discount. The benefit to the entity is a return on capital as opposed to the pure cost of purchasing allowances. The benefit to the state is leveraging private capital that would not happen if the state decided to invest C&T revenues itself in the same project. Also, participating entities would have a very strong financial incentive to make sure the project is successful.

Alternatively, the state could choose to invest funds from the sale of AB32 allowances into in-state low carbon fuel projects. This approach would work within the existing constructs of the AB32 program, building confidence in the longevity of the C&T program. However, diverting C&T revenue requires the state to assume all risk and dedicate a significant portion of AB32 proceeds to be used for biofuel production. Also, with no potential investment upside for regulated parties, this does not motivate industry to become enthusiastic investors in renewable energy technologies. This solution would be possible if the state made the goal of meeting one-half of LCFS reduction targets through the use of C&T funds. If California scales up its C&T investment allocation into biofuels and provides sufficient capital to meet LCFS goals, it could become the primary investor in in-state biofuel facilities.

Estimated Cost of C&T Compliance

To calculate the cost of compliance, we use a low price of \$15/ton for allowances/offsets and a high price of \$30/ton. We multiply this by the expected emissions from gasoline and diesel fuels. We also assume approximately 75 percent of allowances will be freely allocated to refiners between 2015 and 2017, and 50 percent thereafter. After adjusting for these cost reductions, we obtain a low-end industry-wide cost of compliance between 2015 and 2020 of approximately \$6.8 billion and a high-end estimate of \$13.7 billion. Leveraging a portion of these funds could materially improve the production capacity of in-state low carbon fuel production and lower the risk of meeting the 2020 LCFS target. For example, the state could require \$2 in investment for \$1 credit in allowances.

With a range of \$3.75- \$15 billion in capital costs to build California production facilities using in-state biomass, this could require 50 percent or more of the proceeds from fuels in the cap, or alternative compliance credits.

Since early investments are likely to have added impact on long-term GHG benefits, an additional incentive for early investment could provide the necessary cash flows for significant biofuel scale. Incentives might include a longer period of time to demonstrate GHG abatement, discounted or waived penalty fees in the case of project failure, or lower cost of investment versus number of allowances.

Benefits and Drawbacks

An alternative compliance mechanism allows obligated parties under the cap to forgo some allocation purchases and instead put capital into a qualified biofuel project, so C&T auction revenues will be lowered. Such changes to AB32 during the implementation period could be difficult and undermine confidence in other aspects of the program remaining unaltered, therefore lowering investor certainty. Also, the impact to credit prices is unclear, and this could penalize parties that chose to invest in future AB32 credits early. Since AB32 has no stated goal of revenue generation, we find private market allocation could be an efficient and leveraged use of funds. As compared with public funding of energy projects, allowing an alternative compliance mechanism places all the risk on the private sector. Fuels under the cap will have a vested interest in successful biofuel production. The state will avoid having to identify particular companies to support, as market forces will determine which projects succeed.

LCFS Enhancements

The Low Carbon Fuel Standard is already sending market signals to lower the carbon intensity of fuel in California. The following concepts could better facilitate the goals of the program, which are to lower the emissions from the transportation sector, and introduce alternatives to fossil fuels.

Price Collar – Minimum and Maximum Prices for LCFS Credits

As a market-based program, the LCFS does not currently set a floor or a ceiling on credit prices. However, it could provide a more steadfast market signal if credits were priced within a set range. As examined in the recent UC Davis paper, the upper limit of the collar would assure obligated parties could meet carbon requirements at a reasonable price, while the program has a minimal (if any) effect on consumers. The lower limit of the collar would provide guaranteed cash flow for alternative fuel providers, which is critical to investors considering scaling an alternative fuel.²⁰ This minimum could be set below current credit prices, so there would not be any tangible impact on prices. The intended impact would only be more investor certainty. Much like setting a minimum price on AB32 credits, Air Resources Board (ARB) retains the authority to name a minimum credit trade value for all transactions reported. In turn this would help create the new markets intended by the LCFS. In the chance of a crash, or oversupply of fuels and credits to the state, lower limits would have the tradeoff of price supports through the duration of the program or crash. In the event of its enforcement, a floor should be set low enough not to induce tangible burden on fuel prices at the pump.

The federal Renewable Fuel Standard has volumetric mandates for biofuels, which effectively sets a price floor. This floor has been responsible for the majority of biofuel investments to date. For the LCFS to set a similar investment signal, price minimums must be set even below current market rates.

The maximum price would be set by defining a maximum cost per gallon, using the number of credits that will be needed for a particular year, then determining what maximum credit price would stay below the maximum retail cost impact assuming the entire cost was passed on to the retail price. ARB is currently examining methods to introduce a price ceiling, as well as studying their impacts. If the ceiling price is set too low, some low carbon technologies may not receive the necessary credit price to come to market. Also, capping LCFS credit prices may limit revenue streams to alternative fuel producers. However, setting the ceiling is an important tradeoff, since it can alleviate impacts of any unintended price spikes related to the LCFS.

Overall, the downside of minimum and maximum prices is the removal of the free market value of LCFS credits. As the LCFS extends beyond 2020, investor certainty will stabilize, and ideally this price collar would expire.

²⁰ Lade, Gabriel and Lin, C.-Y. Cynthia The Economics of California. Cynthia Cost Containment Mechanism, UC Davis 2013. Available at : http://www.its.ucdavis.edu/research/publications/publication-detail/?pub_id=1996

Expansion of Credit Trading Market

Currently the trading platform by the LCFS is updated on a quarterly basis by CARB, and only allows trading by obligated parties. Expanding the electronic trading platform to include non-obligated parties would create more transactions on a real-time basis. Credit values will be more transparent and liquid. Third-party transactions can provide an opportunity for some credits to be sold below market prices, thereby lowering compliance costs for some obligated parties. Ideally this platform ideally could be the same as used for the federal Renewable Fuel Standard, thereby better harmonizing the two programs.

This concept would also allow the introduction of green credit banks into AB32 or LCFS. While not assessed in this paper, a green bank would be similar to a state-level loan guarantee program.²¹ These programs are gaining popularity after the launch of the New York Green Bank²² and require carbon credits to be traded by third parties.

With an expanded credit market, the State retains its power to scrutinize all credit trading through its quarterly reconciliation with an optional ARB authorization of credits and transactions. Only registered parties would be able to participate in the credit market. To register one is subject to California state law. This provides enforcement power to ARB, in lieu of devoting resources to market brokering. Private companies with trading platform capabilities could provide their services at no cost to the state by recouping small fees on each transaction.

Key Elements

- The registry of credits would be under the jurisdiction and operated under the rules determined by ARB. This registry would clear every deal from a regulatory perspective.
- A separate and secure connection to trading system(s) with multiple service providers would allow the purchase and sale of verified LCFS credits. The exchange platform would handle the price discovery and financial aspect of the trades.
- Competition among private trading system service providers would encourage more participation and better service to the parties participating in trading.
- ARB becomes the regulator and overseer of the market, not the broker. This would alleviate a large resource burden on ARB once the market is functioning. In addition, it would reduce the legal risks to ARB since solicitation of trades and completion of transactions would not involve ARB.

²¹ <http://www.bloomberg.com/news/2013-03-19/california-cap-and-trade-funds-proposed-for-green-bank.html>

²² <http://www.governor.ny.gov/NYGreenBank>

Appendix A: Biomass Pathway Assessments

Pathways are defined by the feedstock used to produce the biofuel. Several biofuel production processes can convert the feedstock to fuel, or a single process can work on multiple feedstocks. Our intent is not to provide an exhaustive analysis of this feedstock-process matrix but to show some promising examples that could be deployed in California.

We describe pathways to low-carbon fuel production and the state of development of commercial production facilities. A full analysis of each pathway would require knowing:

1. The capital required to build a gallon of production capacity (\$/gallon of capacity);
2. Operating cost to produce a gallon of fuel;
3. The carbon intensity of the fuel produced (g/MJ) and;
4. The approximate cost for a gallon of low carbon fuel (before blending) derived from the operating costs and capital related costs (cost of capital and the expected rate of return.)

While some of this data is publicly available, much of it is not. From our interviews with many of the companies working on production facilities combined with publicly available data and NREL estimates, we found a large range of capital requirements between \$3.5 and \$20 per gallon of production capacity but we believe \$5 - \$20 per gallon is more likely. Thus for 1 billion gallon capacity, the private investment is between \$5 and \$20 billion dollars. All companies describe their fuels as being competitive with fossil fuels (assuming \$100/barrel oil), and some processes look to be very competitive.

We will also look at the challenges to utilizing these feedstocks, and assess solutions for California to recognize the related benefits of in-state biofuel production.

Pathway 1: Oils to Renewable Diesel

Pathway 1 uses waste oil and converts it to renewable diesel. This is currently the largest production pathway for drop-in fuels.

Advantages: In Production, Low Emissions

Currently the only advanced, drop-in biofuel commercially available in the United States is renewable diesel from waste oils. Renewable diesel pathways from waste oils under the LCFS show a range of carbon intensities from 5-40 g/MJ CO₂e, or roughly a 58-95 percent reduction in emissions.²³

Challenges: Availability of Oils

Availability of waste oils is limited. Current U.S. capacity is 212 million gallons per year. In California, animal tallow is underutilized, and could have a carbon intensity of 19.9 g/MJ. Furthermore, corn oil byproduct from ethanol facilities produced at any location could be among the lowest carbon intensities available on the market, as renewable diesel from corn oil has a pending carbon intensity of 6 g/MJ (94 percent reduction).

Example 1: Diamond Green

Run as a joint venture between Valero and Darling. The 137-million-gallon facility opened in June 2013 in Louisiana.²⁴

Example 2: Neste Oil

Neste announced intentions to deliver 100 million gallons of renewable diesel to the United States in 2013 from facilities in Finland and Singapore.²⁵ Neste uses multiple feedstocks. It has issued an off-take agreement to Cellana for algae oil. It also processes Australian tallow in its Singapore facility, up to 100 million gallons per year.

Example 3: Dynamic Fuels

Dynamic Fuels has a facility that has been commercially operable since 2010 with a capacity of 75 million gallons. Dynamic was started as a joint venture between Syntroleum and Tyson Foods, but has been stalled since October 2012 due to a partnership discord. The facility may be re-started as all Syntroleum assets were recently acquired by Renewable Energy Group.

²³ <http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/dgd-sum-120112.pdf>

²⁴ <http://www.darpro.com/diamond-green-diesel>

²⁵ Neville Fernandez of Neste Oil, in a letter to the California Senate Transportation and Housing Committee, 18 March 2013.

Economics:
Capital expenditures

Facility	Capital Costs	Capacity (MG/yr)	Capex/Gal
Neste - Porvoo	130	56.76	\$2.29
Neste - Porvoo	130	56.76	\$2.29
Neste - Singapore	725	240	\$3.02
Neste - Netherlands	1000	240	\$4.17
Dynamic - LA	150	75	\$2.00
Valero - LA	330	137	\$2.41
UPM - Finland	200	30.888	\$6.48

Table 4. Capital expenditures from seven worldwide facilities. Taken from E2 Advanced Biofuel Market Report 2013.

Table 4 shows capital expenditures for the seven existing renewable diesel facilities worldwide. Some of these fuels are sold into the California market. The capital costs range from \$2.00-\$6.48/gallon. Applied to availability of California fats, oils and greases, this is a range of \$109-\$352 million dollars, with a mean of \$230.8 million.

Renewable diesel does not have any stated operating costs, however market analysts have calculated roughly a \$3.68 operating cost per gallon, based on a \$0.36/lb feedstock price for yellow grease.²⁶

26 <http://seekingalpha.com/article/1339451-biodiesel-economics-101-understanding-the-margins-part-2>

Pathway 2: Municipal Solid Waste to Fuel

Municipal solid waste (MSW) is comprised of multiple types of materials. A portion of the organic material that is currently going into landfills is more suitable for conversion to fuel. Other materials may be more appropriately recycled or converted to compost.

Advantages: Reduced Waste, More Recycling

Diverting landfill matter to energy conversion could help municipalities create low-carbon transportation fuel, avoid the long-term environmental consequences of landfills, and reduce the cost of their waste disposal.

Municipal solid waste is already collected across the state. Advanced sorting technologies can provide improved separation of materials. To this end, Governor Brown's 2014 budget allocated \$30 million of Cap and Trade funding towards recycling, composting, recycled-content manufacturing and organic waste-to-energy projects.²⁷

California Landfilled Waste Stream by Material Type, Post Recycles (ADC not included)

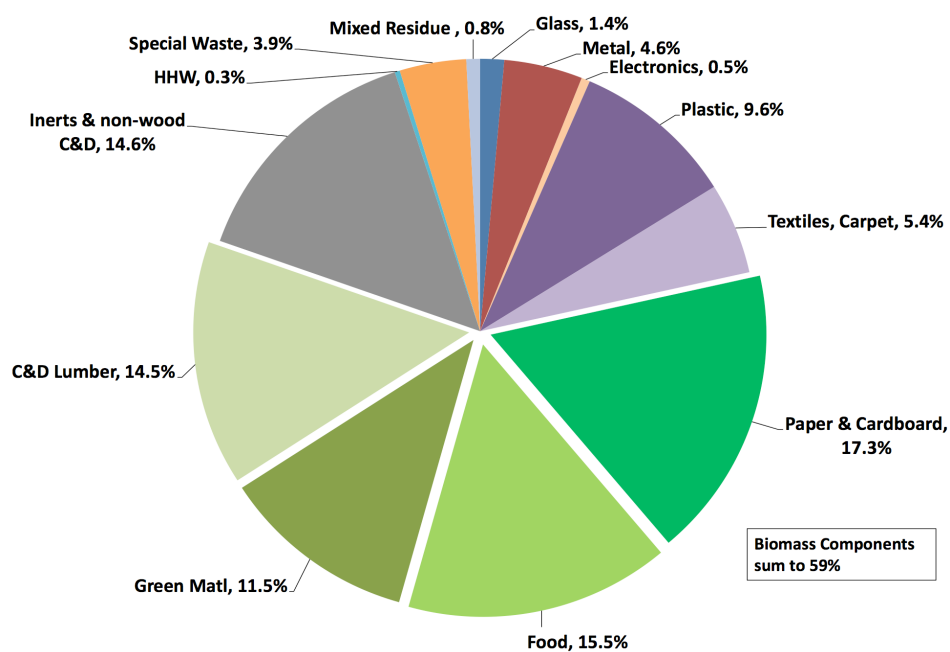


Figure 2.

Breakdown of municipal solid waste streams by material. ADC = alternative daily cover

²⁷ http://cawrecycles.org/whats_new/recycling_news/jan9_pr_gov_budget

Challenges: Legislative Definitions, Demand

Waste conversion contracts must be designed carefully, so as not to put any demand pressure on waste streams, thereby unintentionally incentivizing waste creation. Existing waste conversion technologies need to demonstrate that air quality concerns are alleviated by the improvements to the technologies in recent years.

California legislative definitions of waste streams and acceptable technology need to be updated, and incentives for fuel conversion in preference to landfilling must be introduced. Currently, there is little distinction between different conversion types or biomass types.

Example 1: Gasification by Sierra Energy

Sierra Energy can utilize a myriad of feedstocks to produce renewable diesel, gasoline or ethanol. Sierra has a demonstration plant in Sacramento and a contract with Fort Hunter Bragg for a second facility.

Technology: Gasification is a process by which materials are heated until they decompose to a mixture of simple gases, mainly hydrogen and carbon monoxide. The gases are then converted to a liquid fuel at lower temperature over a catalyst (See full description in Box 1.)

Box 1

Technology: Sierra Energy's gasification process heats feedstock - to very high temperatures (~ 900°C), generated by partial combustion of the feedstock, to produce "flue gas", a mixture of hydrogen and carbon monoxide. The temperature is important because it drives both capital cost and GHG emissions. This gas is then converted at lower temperature (~ 200 to 300°C) over a catalyst to liquid fuel.

Economics: Assuming a feedstock cost of \$75/dry short ton, NREL predicts \$8/gal gasoline pricing for early plants falling to \$4.50/gal for the nth plant. However, Sierra Energy may attain lower costs thanks to MSW (only \$50-70/ton).

Example 2: IH2 hydro-pyrolysis Process by CRI Catalysts

CRI Catalysts²⁸, a wholly owned subsidiary of Shell Oil, is commercializing the IH2 process for a multitude of feedstock types. They have expressed interest in using the process for waste-to-fuel conversion at MSW facilities.

Technology: Hydro-pyrolysis is a process by which materials are heated to a lower temperature than gasification in the presence of hydrogen to obtain a liquid. (See full description and detail in Box 2).

²⁸ <http://www.criterioncatalysts.com>

Box 2

Technology: IH2 uses a hydro-pyrolysis technology. Pyrolysis (vs. hydro-pyrolysis) is a process of heating biomass until it partially decomposes to a liquid (temperature ~ 500°C). The resulting pyrolysis oil is not suitable as a fuel because it contains much of the oxygen from the feedstock which reduces the energy available for fuel combustion. The oxygenated compounds in the pyrolysis oil have to be converted to hydrocarbons by heating in hydrogen in the presence of another catalyst. (see the description of the KiOR process below under the Woody Biomass pathway)

Hydro-pyrolysis is a new variation of the pyrolysis concept, developed by The Gas Technology Institute called IH2 hydro-pyrolysis, in which the biomass is heated in a hydrogen atmosphere at 350 to 480°C, in the presence of a catalyst, to liquefy and deoxygenate the biomass at the same time. The resulting liquid is much closer to a high energy content fuel but some back-end chemistry development may still be required. Note that the hydrogen used in the process is generated from methane and other light gases emitted during the heating process by high temperature cracking. This is an expensive step per unit processed, but only a small fraction of biomass is involved, so cost is manageable.

Economics: NREL estimates operating costs at \$1.64/gal minimum (break-even) pricing for nth plant.²⁹ Capital costs can run \$116/dry ton of feedstock or \$3.50/gallon of production capacity. Hydro-pyrolysis could be applied to MSW components and to agriculture/forest residues.

²⁹ Tan, E. C.D., Marker, T. L. and Roberts, M. J. (2013), Direct production of gasoline and diesel fuels from biomass via integrated hydro-pyrolysis and hydroconversion process—A techno-economic analysis. Environ. Prog. Sustainable Energy. doi: 10.1002/ep.11791

Pathway 3: Agricultural and Forest Residue to Fuel

Woody biomass and agricultural residues can be converted to renewable gasoline or diesel through several different processes. Over the last year, production facilities have started operations across the United States.

Advantages: Jobs, Forest and Crop Maintenance

California has immense wood resources at its disposal, with about 40 million acres of forest. The U.S. Forest Service manages over 18 million acres, with the remainder owned by the Bureau of Land Management, the National Park Service, or private ownership.³⁰ Mill residues, in addition to forest operations such as logging, thinning, fuel reduction programs and ecosystem restoration create 27 million bone dry tons of excess woody biomass. Of this, 14.2 million bone dry tons could technically be converted. However, new research is ongoing to determine what portion of this 14.2 million tons may be converted economically.

The greatest opportunities exist at sawmills, where aggregated woody biomass is available in the form of bark, sawdust, wood chips and wood shavings. Currently the biggest users of this biomass are biomass power plants at \$36.70 per bone dry ton.³¹ Production of motor fuels could have a higher economic value, since comparable feedstocks are typically more expensive. Furthermore, forest biomass is frequently gathered and burned, creating pollution and wild fire risk. This expensive prescribed burn process is a low value use for a rich biomass source. When economically feasible, the use of this excess forest biomass as a feedstock may provide healthier forests and lowered emissions.

On farms, excess agricultural biomass could be collected and sold, thereby generating new revenue for farmers. While some portion of leftover biomass is left on fields as compost material, up to 50 percent of residue (or 3.5 million dry tons) could be recovered without soil impacts or yield loss (dependent on soil, location and crop).³²

Challenges: Aggregation, Permitting

Aggregating woody biomass from the northern part of the state is the biggest challenge and expense to biofuel production. Since the biomass already aggregated at sawmills is already in use by biomass power plants, this is not a likely source of wood. Moving woody biomass is typically economical within a 50-mile radius depending on the business model.

California's permitting processes are more numerous and cumbersome than many other states'. Biofuel producers have opted to locate facilities in states where permitting is expedited and less

³⁰ http://ucanr.edu/sites/WoodyBiomass/Woody_Biomass_Utilization_2/The_Resource/

³¹ http://web1.cnre.vt.edu/forestry/cofe/documents/2013/Bisson_Han_Han.pdf

³² <http://www.energy.ca.gov/2013publications/CEC-500-2013-052/CEC-500-2013-052.pdf>

expensive. In addition, [other states](#)³³ are offering grants to entice companies to locate their refineries inside their boundaries.

Example: KiOR

KiOR has a 13-million gallon facility operating in Mississippi, and has announced plans to construct a 40-million gallon facility in 2014 at the same location.

Technology: KiOR uses a pyrolytic catalytic cracking process and hydrotreating to produce renewable diesel and gasoline. (See Box 2 above.)

Economics: Capital expenditures for a KiOR facility, which co-locates at shuttered paper mills to produce renewable gasoline and renewable diesel, run at about \$10/gallon of installed capacity.³⁴ The existing KiOR facility in Mississippi cost about \$220 million for a 13 million gallon capacity. KiOR has long-term plans to build an 80-million gallon plant at a cost of about \$810 million.

KiOR's public disclosures report an unsubsidized operating cost of \$1.80/gallon. To reach this level of economics, KiOR needs to process 1,500 bone dry tons of wood chip per day, and to continue to improve its conversion efficiency. This price assumes a cost of \$72.30/ton for the woody feedstock.

For comparison, the Pacific Northwest National Laboratory (PNNL) modeled³⁵ the cost of pyrolysis with pyrolysis upgrading in 2009. Their projected price was \$7.68/gallon. With significant reduction of the cost of upgrading, the DOE predicted that by 2017 the minimum price could drop to \$2.32/gallon.³⁶ Given the capital and operating costs a simple internal rate of return model predicts a minimum price of \$3.50 to \$4.20/gallon depending on discount and interest rates.

Other companies working on a similar fuel pathway include: ZeaChem (lab in California and developing ethanol project in Oregon), LanzaTech, Mascoma, ZeaChem, Envergent, Haldor Topsoe, and Woodland Biofuels.

³³ <http://www.kior.com/content/article.php?Article=1&s=2&s2=35&p=35&t=News-and-Events>

³⁴ E2 Emissions Reduction Model, KiOR tab

³⁵ http://www.pnnl.gov/main/publications/external/technical_reports/pnnl-18284.pdf

³⁶ http://www.biomassboard.gov/pdfs/tac_design_case_haq.pdf

Pathway 4: Biomass to Sugars to Fuel

This process pathway comprises a number of process and feedstock options. All of these feedstocks and processes have the commonality of producing sugars from biomass and converting those sugars to fuel. Although proven feedstocks include woody biomass, switchgrass, energy cane, sugar beets, corn stover and much more, availability of sugar is a limiting factor for the production of fuels. The land used for these feedstocks should not compete with food production, so sourcing considerations are important.

Algae can produce oils from carbon dioxide and sunlight but such processes are not currently close to commercialization. However, algae can also produce oils from sugar. Solazyme has commercialized this process, though their first market is high-value oils rather than fuels. Some companies are converting woody biomass to sugar using enzymes. Many of these companies then use a fermentation process to produce cellulosic ethanol. The sugar to oil to biofuel is also under development.

Advantages: New Economic Value, Flexible End Products

Sugar may be extracted from virtually any cellulosic material, including purpose-grown energy crops and agricultural waste. Purpose-grown energy crops might only be pursued in limited scale in California, since most fertile land has higher value for food production. However, agricultural residue is a waste product that is currently deriving no economic value. As mentioned previously, California Biomass Collaborative estimates that about half of agricultural residue can be removed without impacts to the soil.

Companies pursuing sugar-to-fuel processes may help buoy early revenues by producing products with similar processes but higher margins like chemicals or specialty oils.

The sale of agricultural by-products like residue could generate new incremental revenue to rural economies. As an example, Abengoa Bioenergy is paying \$17 million per year for 438,000 tons of cellulosic feedstock within a 50-mile radius of its Kansas facility.³⁷

Challenges: Maturity of Technology, Other Markets

This remains the most immature pathway although many companies and research labs, including Joint Bioenergy Institute have put significant research and development towards optimizing it. Most commercial production has gone to other renewable-oil markets instead of fuels due to higher-profit margins at lower scale. Several companies have stated intentions of scaling higher-volume, lower-margin fuel capacity in coming years.

³⁷ http://www.abengoabioenergy.com/web/en/prensa/noticias/historico/2012/bio_20121113_2.html

Example 1: Amyris

Technology: Yeast fermentation of sugars. About one-third of current production goes to renewable diesel production with planned expansion into jet fuel in 2014.

Economics:

Capex

Not publicly available

Opex

\$5/liter of farnesene production in Q3 of 2013, with expected drop to \$4/liter in Q4 2013. This was a decline in cost from \$12/liter at the outset of 2013.³⁸

Example 2: Solazyme

Technology: Solazyme's business model feeds the sugars to algae in heterotrophic bioreactors, with the algae producing oil which can be refined into petroleum products.

Economics: Solazyme's disclosed capital costs are about \$5.11 per gallon, bringing the total process cost to \$9.27 per gallon of production capacity.³⁹

³⁸ Amyris 2013 Third Quarter Financial Results

³⁹ E2 capital costs model, Solazyme tab. At \$5.11/gallon for Solazyme capex + \$4.16 for Sweetwater's biomass to sugar process, total capital expenditures is \$9.27/gallon.