Final Draft Contractor Report submitted to CEC

TASK 10a:
Feedstock and Infrastructure Assessment and Biorefinery Case Studies for Biofuels Production in California

Comprehensive Executive Summary

Task 10 contains two separate research analyses. Part One is Agricultural Sources for Biofuels in California. Part Two is Forest Woody Biomass Potential for Biofuel Production. Each analysis contains its own executive summary.

Part 1: Agricultural Sources for Biofuels in California

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Executive Summary

Use of crops and crop residues as feedstocks for the manufacture of liquid transportation fuels increases the supply and diversifies the sources of these fuels, creates domestic supplies, industries and jobs, spares petroleum, and may result in reduced greenhouse gas (GHG) emissions from alternative transportation fuel use. But using crops for energy may also raise the price of other crops, not just those used for energy feedstocks, making annual crop production more profitable, but livestock production less. Uncertainty about the best crop and residue sources for biofuel production, the best technology for its manufacture, the interactions among crop type and technology, the effects of uncertain, future public policies, and the future global supply, availability and price of oil together make it difficult to predict the best approach to the use of crops and residues for biofuels. The California Energy Commission (The Commission) and the California Air Resources Board (CARB) both have policies affecting biofuel production and use in California and would benefit from an assessment of the diverse consequences of those policies on the in-state production and use of biomass for fuels and power. In California, biomass from urban sources, forests and agriculture is abundant, but not equally accessible (http://biomass.ucdavis.edu/). Part A (TASK 10) of this assessment focuses on new agricultural feedstocks, specifically crops that have a reasonable likelihood of being produced in the state for energy purposes, and more specifically selected businesses currently in development or likely to emerge as fuel providers in California based on such sources. Winter oilseed crops as biodiesel feedstocks are compared to the availability and price of residual or waste sources of fats, oils and greases also used for biodiesel. Discussion of waste or residual resources from agriculture, including livestock manures and rice straw are also reviewed, particularly as feedstocks for compressed natural gas as a transportation fuel. Part 10B focuses on forestry biomass and identifies the most concentrated sources and likely locations for biorefineries based on these resources, and prices for their use and for fuels derived from them.

Likely sources of in-state agricultural biomass differ in part from those emphasized elsewhere in the US. The crops considered most likely to find near-term use in California include winter annual oilseeds (canola and Camelina), sugar (energy) beets, sweet sorghum, grain sorghum, sugarcane, and energy cane. Current in-state ethanol companies are particularly interested in grain sorghum (for advance ethanol) and biodiesel companies in oilseeds for biodiesel or advanced fuels like jet fuels. All of the crops identified can be produced efficiently in California with very high yields, are well-known to farmers, are compatible with current farming systems and mechanization, and can be produced at relatively low levels of GHG emissions per unit of fuel, based on attributional life cycle assessments. Crops commonly mentioned as bioenergy feedstocks at the national level like switchgrass and Miscanthus have little chance of being grown in California because unlike sugarcane, they are difficult to convert to fuel, will use a large amount of water due to their perenniality, and will not produce yields sufficient to compensate for these disadvantages. As perennials, they will have a larger effect on crop displacement than simple annuals, which allow rotation with and complement other crops. Agricultural residues like livestock manures have energy potential and some other residues like prunings from almonds and other fruit and nut trees already have a role in the production of electricity in California and are discussed elsewhere in other California Biomass Collaborative reports (Amon et al., 2010; Zhang and Kaffka, 2014). Rice straw is the most significant agricultural residue and has also been discussed elsewhere (Kaffka et al., 2012), but is summarized here for comparison with new, purpose-grown crop-based sources.

The amount of irrigated farmland in California has declined over time, due to land development for alternative uses, primarily urban expansion, and more significantly from loss of water for irrigation due to water policy changes and drought. Crop shifting is a common occurrence in the state's dynamic farming systems as new crops are adopted and less profitable ones are abandoned. Over the last decade, a substantial shift has occurred from annual crop production to perennials like nuts and grapevines. This has reduced the amount of land and water available for other crops, but also presents an opportunity for feedstock production during winter periods on some portion of the same land. Based on analyses of Pesticide Use Report data from the California Department of Pesticide Regulation, within arable cropping systems, between 5 and 10 percent of irrigated cropland (approximately 450K to 900K acres) characteristically has been shifted annually in and out of temporary fallow and into new crops of all kinds. Biomass feedstock crops would be a new use for this fraction of farmland in California. This analysis indicates that bioenergy crop adoption levels for most of the crops evaluated here are small relative to the total land cultivated in the state in an average year, and under favorable assumptions, would approximately equal the amount of land that shifts readily into new crops within the state. We suggest that small-scale changes in land allocation primarily involve fallow land, underutilized resources, or are accommodated with only small consequences for crop acreage of commodity crops likely to influence land use elsewhere. Since land often is fallow in California due to water policy and drought, it is difficult to establish a land use baseline for farming. The effects of changing land use due to bioenergy crop adoption are overshadowed by other, far more significant factors. Drought and variations in water supply to agriculture in California based on policy effects have significantly greater effects on land use than the modest levels of crop shifting anticipated due to bioenergy production discussed here, with the possible exception of the Imperial Valley, where at least two firms plan to establish biofuel businesses based on the use of perennial grasses.

Indirect Land Use Change (ILUC) is the term used to describe the effects of agricultural markets on land use worldwide resulting from land diversion from current uses to bioenergy feedstock production. This change cannot be measured directly but is inferred from complicated, global scale models. Additional carbon costs for crop-based feedstocks are based on calculations of these effects, and can influence the chance of crop-based bioenergy businesses to develop in California. Low ILUC values are important economically if California producers are to be successful. The model used in California for this purpose lacks sufficient detail to measure the level and types of changes identified and foreseen by this analysis, which attempts to account for detailed local land use patterns and farming conditions. Complicating land change calculations in California is the significant influence the loss of reliable irrigation water supplies has on in-state production. An unknown but large number of acres, probably exceeding 500,000, will be idled in 2014 and an unknown but large amount of cropland also will be adversely affected by deficit irrigation. If the drought and the current water policy framework persists, then even greater losses will be observed in future years and reduce the chance for agriculture to participate in climate change solutions. Changes due to bioenergy feedstock production estimated to occur here will affect land use and markets far less, implying that appropriate ILUC values will not significantly influence fuel CI calculations andshould be close to zero. The Bioenergy Crop Adoption Model (BCAM), relying on robust predictions of land use within regionalized cropping systems, provides the most accurate current prediction of potential farmland uses in California if biofuel feedstock crops are grown. Crop adoption varies across the state by crop and region, as do the crops displaced. These predictions are a better basis for accounting for potential land use effects than other current models used for this purpose, which cannot account for the state's remarkable heterogeneity. Widespread farming and crop rotation practices in California continuously support new crop adoption opportunities in the state's agricultural systems (for any purpose). This results in more efficient total resource use when new crops are adopted. A history of compensatory yield increases among many crops also contributes to the conclusion that in-state feedstock production is likely to have small to no market-based effects within or outside the state. This should provide in-state producers an opportunity to be lower CI feedstock producers, compared to others who rely on common agricultural commodities and locations and derive their feedstocks from markets with well-developed trade channels. As a consequence, in most cases, ILUC values may be close to zero. Attributional LCA tracks energy and material flows associated with bioenergy crop production. Consequential LCA estimates the wider effects of feedstock production on GHG reductions at the level of the economy. Estimates for ALCA are reported here. If crops are produced using best management practices and achieve high yields, ALCA values tend to be low relative to other reported values in the literature (mostely less than 30 gCO_2eq/MJ) and low enough to support the production of low carbon intensity fuels, estimated only on a feedstock basis.

Three sample biorefineries were modeled using the IMPLAN model to assess the economic consequences of creating new businesses in rural, disadvantaged areas. These included a biodiesel producer using FAME technology, an energy beet to ethanol facility, and a sugarcane biorefinery. Economic effects are site specific but large in all instances. When construction, operation and secondary and tertiary effects are considered, each facility contributed significant economic advantages where they were built and for the state as a whole. These new businesses are among the best ways to distribute the anticipated positive economic effects of the state's climate change policies in rural regions. The production of bioenergy feedstocks will displace modest amounts of other crops, and require natural resources like water, but the actual benefits to the public will outweigh these other effects.

Based on the case studies included here, and under favorable assumptions about crop yields, water availability, and the availability of capital for biorefinery construction, the potential for in-state fuel production under favorable circumstances for all enterprises amounts to approximately 200 Mgge/y for new sources, and an additional 25 Mgge/y for in-state grain sorghum feedstocks, which replace use of imported corn grain, without affecting total biofuel supply. The use of grain sorghum by the state's three existing ethanol companies would not increase in-state fuel production, but substitutes feedstocks (sorghum for corn), with approximately equivalent fuel output. There are other firms attempting to develop new sources of fuels that are not considered here. For example, fuels made from biogas from diverse sources, a second energy beet enterprise in the Delta region with a production target of 30 to 40 Mgal/y of ethanol, and others that may not have made public announcements of plans. Most of these firms claim fuel CI values in the 20 to 30 g CO_2eq/MJ range, approximately equivalent to the most efficient values reported for Brazilian sugarcane, (minus ILUC), which would likely be the principal economic competitor for in-state biofuel production. A large value for ILUC GHG effects added to in-state fuels would act as a significant barrier to in-state production from agricultural sources. Adopting the LCFS is equivalent to a policy level assumption that the consequences of prudent bioenergy use will be beneficial on the whole, and implies a willingness to accept a range of associated consequences. If local land use and related environmental and social effects can be estimated for individual projects, and if these are found to be non-harmful or desirable on the whole, and if few acres of incumbent crops are likely to be displaced, then market effects are likely to be inconsequential, minimizing risks associated with indirect land use change (ILUC) as well. In that case, GHG savings from biofuels are likely to be real. Policy instability is a significant barrier to both innovation and new investment in the state to produce low CI biofuels with their diverse GHG reduction and social and economic benefits.

Motivation

The goal of this task is to provide the California Energy Commission with case studies of potential biomass feedstock sources in California from agricultural and forest derived biomass. Individual case studies for agricultural biomass were suggested by the Energy Commission, applications to the ARFVPT (AB 118) program, by review of potential biomass businesses in California, professional judgment, and consideration of state and federal policies affecting biofuels and bioenergy. Comparisons with residual-based pathways are also provided for comparison.

Task 10 Purpose

The goal of this task is to provide the Energy Commission with case studies of potential new biomass feedstock sources in California. Case studies were suggested by Energy Commission staff, suggested by potential biomass businesses in California, or indicated by important potential policy changes affecting biomass energy in California or at the federal level.

Approach

Identifying likely feedstock crops

The set of possible bioenergy feedstock crops analyzed are derived from several sources. Most important are the self-declared interests of potential bioenergy companies applying for support from the state's ARFVTP. Other sources include expert opinion derived from a technical advisory process supporting agronomic work on new biofuel feedstocks established for the Commission and California Department of Food and Agriculture (CDFA), and contacts between companies and staff at the California Biomass Collaborative (CBC) and other industry and trade associations, and professional judgment.

Land use analysis

Longer term pattern of agricultural land use in California were analyzed using data self-reported by farmers and assembled in the California Department of Pesticide Regulation's Pesticide Use Report database. This data includes crop production and pesticide application identified at the section level (640 square acres). Analyzing this data provides an estimate of crop frequency over time by location across the state, which is interpreted here as incumbent land use or incumbent cropping systems. New crops must displace one or more incumbent crops. Regionally diverse cropping patterns are identified using this data. Additional data from the National Agricultural Statistical Service (NASS) and county agricultural commission reports are also used to help make a more complete picture of actual land use or to check on results based on PUR data.

Economic assessment of potential agricultural feedstocks useful for biofuels

The Bioenergy Crop Adoption Model (BCAM) is used to evaluate the most likely locations and adoption prices of new feedstock crops across California based on an optimization model developed for cropping systems derived from PUR data analysis. Entry prices and acres adopted for the crops evaluated are reported by region and sub-region (cluster). In complex cropping systems, changes in one crop affect a range of several other crops as well, with some being displaced and others expanding. BCAM identifies the crops displaced and additional new crops adopted locally or regionally as a consequence of bioenergy crop production.

Indirect Land Use Change (ILUC) is the term used to describe the effects of changes in agricultural commodity markets on land use worldwide. For biofuel crop production, land diversion results from changing crops from current uses to bioenergy feedstock production. ILUC cannot be measured directly but is inferred from complicated, global scale economic models. The model used in California for this purpose has improved over time but still lacks sufficient detail to measure the level and types of changes identified and foreseen by this analysis. Results from the BCAM model estimate more robustly shifts in land use due to biofuel crop adoption than any other method currently available to the Commission or CARB.

Employment and economic effects of biofuel feedstock production and manufacture

Allocation of a limited amount of irrigation water for feedstock production for biofuels or biopower results in high quality job creation in predominantly rural areas and benefits underserved populations. Agricultural businesses employ a large number of people in feedstock production, assembly and transport, and result in permanent manufacturing jobs, often in rural areas with underserved populations. Estimates of jobs associated with biorefinery production are provided here using as examples some of the possible biorefinery projects identified in this analysis. Input-output (IMPLAN) analyses are reported for potential energy beet, biodiesel and sugarcane businesses as examples to project direct, indirect, and third order economic effects in the communities where these biorefineries may be established.

Lifecycle assessment

Attributional Life Cycle Assessment (ALCA) tracks energy and material flows associated with bioenergy crop production. Consequential LCA (CLCA) estimates the wider effects of feedstock production on greenhouse gas reductions at the level of the economy. Estimates for ALCA are reported here from diverse sources. Possible CLCA affects are discussed.

Potential in-state biofuel production

Based on results from BCAM modeling linked to current patterns of agricultural land use and recent prices, estimates of in-state biofuel production are provided. Barriers to the creation of new businesses are identified, including potential ILUC values and methods for their assessment, and policy instability at both the federal and state level.

Activities performed

1. Identification of likely bioenergy businesses based on crop or crop residue biomass

One source of information about potential crops of interest in California comes from applications made to the state's ARFVTP program (AB118). Multi-feedstock sources listed in Table 2 are primarily recycled fats, oils and grease, and vegetable oils. This list does not include some crops that are frequently mentioned as likely sources like switchgrass, Miscanthus *giganteus*, and Arundo *donax* (giant reed). It is unlikely that low value biomass materials will displace higher valued agricultural crops in California's cropping systems in our view. New facilities in the mid-west processing corn stover into ethanol have recently come on-line in 2014 and one more is due to open late in 2014. These are more complex and costly to operate than starch based processing facilities, but as these facilities improve with time, costs will decline.

Existing biofuel facilities in California are listed in Table 2.The majority are biodiesel producers, currently relying on waste fats, oils and greases for feedstock. To expand capacity, vegetable oils may be needed. The ethanol facilities use primarily corn gran imported from the Midwestern US, but have shifted in part to grain sorghum to take advantage of regulatory benefits associated with the RFS2. They would use in-state grain sorghum if it could be produced for a price that allowed for its conversion to ethanol at a market-based price.

In addition to these sources of information, contacts with most of the businesses attending CEC or CARB meetings related to biofuel and bioenergy issues have been contacted about their plans. Discussions of their plans and options have factored into decisions about likely biofuel opportunities in the state. Lastly, professional judgment about the agroecological viability of differing feedstocks has been considered

Table 1: Recent proposals to the state's ARFVTP program.

Applicant	Project Title	Grant	Feedstocks	Location	Fuel Type/Size	Size	Status
Mendota Advanced Bioenergy Beet Cooperative	Advanced Bioenergy Center Mendota	PON-09-604	Sugar Beets	Mendota	Biofuel ethanol	285,000 gal/year	Awardee
Great Valley Energy, LLC	Feasibility of Fractioned Sweet Sorghum to Ethanol and Products	PON-09-604	Sweet Sorghum	San Joaquin Valley	Biofuel ethanol	3.15 M gal/year	Awardee
EdeniQ Inc.	California Cellulosic Ethanol Biorefinery Utilizing California Waste Products and Feedstocks	PON-09-604	Corn stover, switchgrass, and wood chips	Visalia	Cellulosic ethanol	50,000 gal/year	Not Funded
Alt Air Fuels, LLC	Feasibility Study for Renewable Jet and Diesel Fuels Biorefinery	PON-09-604	Camelina Oil	Seattle	Biofuel diesel	30 M gal/year	Not Funded
California Ethanol & Power, LLC	Sugarcane-to-Ethanol and Electricity Production Facility	PON-09-604	Sugarcane	Imperial Valley	Ethanol and Electricity		Not Funded
Amyris Biotechnologies, Inc	Renewable Hydrocarbon Diesel Production from Sweet Sorghum and Sugar Cane	PON-09-604	Sweet Sorghum	Thousand Oaks	Biofuel diesel		Did Not Pass
Pacific Ethanol Inc.	Madera Combined Heat and Power	PON-09-604	Grain Sorghum	Madera	Cellulosic ethanol	40 M gal/year	Did Not Pass
Pacific Ethanol Inc.	Incorporation of Cellulosic Ethanol Technology into Pacific Ethanol's Stockton Facility	PON-09-604	Grain Sorghum	Stockton	Cellulosic ethanol		Did Not Pass
California Biofuels, LLC	Sweet Sorghum & Agriculture Waste Project	PON-09-604	Sweet Sorghum				Did Not Pass
Mendota Bioenergy, LLC (MBLLC)	Advanced Biorefinery Center-Mendota Integrated Demonstration Plant	PON-11-601	Sugar Beets	Mendota	Biofuel ethanol	285,000 gal/year	Awardee
ZeaChem Inc.	Pilot Plant and Commercial Feasibility Study for Biobased Gasoline Blendstocks	PON-11-601					Awardee
EdeniQ Inc.	California Cellulosic Ethanol Biorefinery	PON-11-601	Corn stover, switchgrass, and wood chips	Visalia	Cellulosic ethanol	50,000 gal/year	Awardee
Canergy, LLC	Pre-Work Low-Carbon Ethanol Production from Sugarcane and Sweet Sorghum	PON-11-601	Sugarcane and Sweet Sorghum	Imperial Valley	Cellulosic ethanol		Not Funded
Pacific Ethanol Development, LLC	Madera Biomass Refinery	PON-11-601					Not Funded
California Ethanol & Power, LLC (CE&P)	Permitting for California Sugarcane Ethanol Plant	PON-11-601	Sugarcane	Imperial Valley	Ethanol and Electricity		Did Not Pass
Partnership for Environmental Progress, Inc.	Agave Biofuel Feasibility Study	PON-11-601					Did Not Pass

Table 2: Existing biofuel facilities in California and feedstocks used.

Category	Plant Name	Gross Liquid Fuel Capacity (MGY)	Project Status	Feedstock
Biofuel-Ethanol	Aemetis Biofuels	55	Operating	Corn/Sorghum
Biofuel-Ethanol	Calgren Renewable Fuels, LLC	60	Operating	Corn/Sorghum
Biofuel-Ethanol	Pacific Ethanol	60	Operating	Corn/Sorghum
Biofuel-Ethanol	Parallel Products	4	Operating	Mixed Beverages
Biofuel-Diesel	Bay Biodiesel, LLC	3	Operating	Multi Feedstock
Biofuel-Diesel	Biodiesel Industries of Ventura, LLC	3	Operating	Multi-Spectrum
Biofuel-Diesel	Blue Sky Biofuels	4	Operating	Waste Oil
Biofuel-Diesel	Community Fuels	10	Operating	Multi Feedstock
Biofuel-Diesel	Crimson Renewable Energy, LP	25	Operating	Multi Feedstock
Biofuel-Diesel	Ecolife Biofuels, LLC	1.5	Operating	Multi Feedstock
Biofuel-Diesel	GeoGreen Biofuels, Inc.	3	Operating	Multi Feedstock
Biofuel-Diesel	Imperial Western Products	8	Operating	Multi Feedstock
Biofuel-Diesel	New Leaf Biofuel, LLC	1.5	Operating	Used Cooking Oil
Biofuel-Diesel	Promethean Biofuels Cooperative Corporation	1.5	Operating	Multi Feedstock
Biofuel-Diesel	San Francisco Public Utilities Commission	0.09	Operating	
Biofuel-Diesel	Simple Fuels Biodiesel, Inc.	1	Operating	Waste Oil
Biofuel-Diesel	Yokayo Biofuels, Inc.	0.5	Operating	Recycled Cooking Oil

2. Land Use Analysis.

Ordination and Classification of California's Main Cropping Systems

Crop choice decisions and production areas were defined by two datasets: the mandatory pesticide use reporting data collected by the California Department of Pesticide Regulation[1] (DPR) and the historical crop land use recorded by the respective County Agricultural Commissioners (CAC). The most important source for frequency of the primary crops grown in California by location within the state was accounted by analyzing data from the Department of Pesticide Regulation's Pesticide Use Report data (CDPR 2014). The date used here are from 2003-2012. This updates an earlier analysis reported in Kaffka and Jenner, 2011. Pesticide use reporting in California was initiated in the 1960s for recording commercial use of specific pesticides. The California Department of Pesticide Regulation implemented full reporting in 1990, and it has become a valuable source of information including pesticide use and other aspects of agricultural systems. Each time a crop is treated with an herbicide, insecticide, fungicide or nematicide, the crop and its location are reported to the database. Data reported by farmers are aggregated on 1 square-mile sections (640 acres, 259 ha). Farming land use information, including types of crop cultivated, acreage planted, and cropping seasons can be queried based on combined filter criteria. This analysis excludes land planted to woody perennial crops, like orchards and vineyards, under the assumption that such areas are not frequently rotated to new crops in response to small marginal changes in crop prices.

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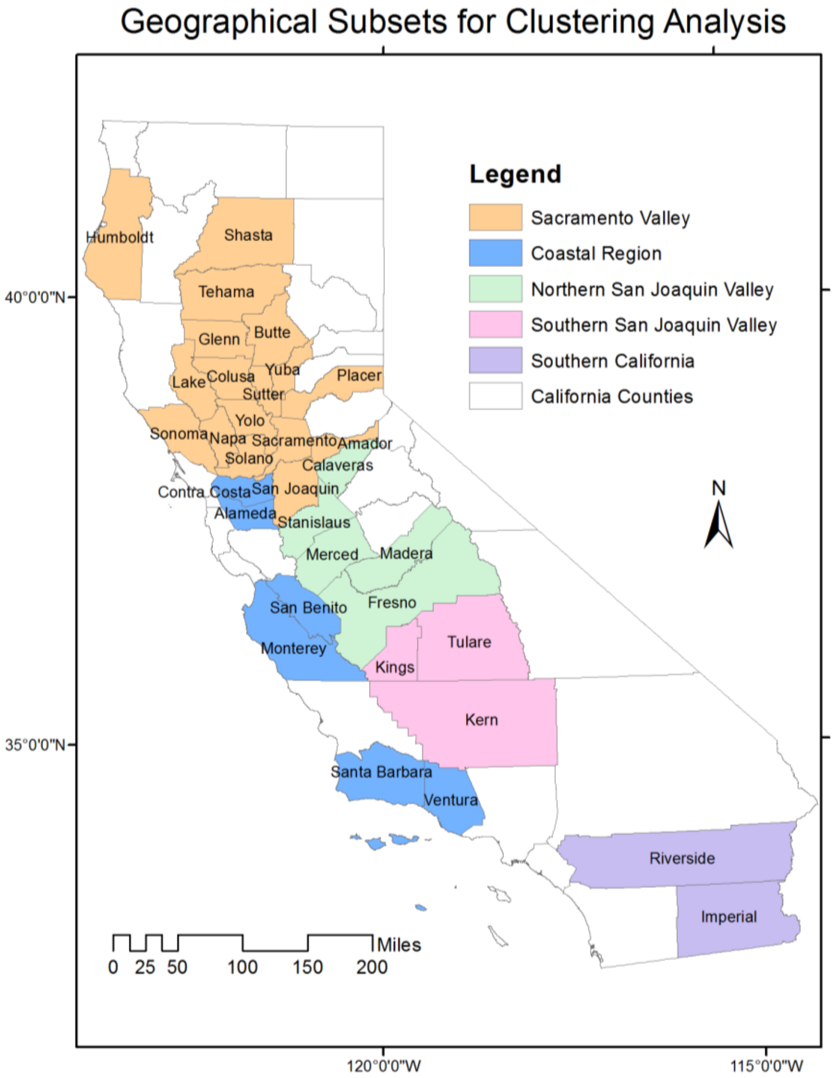
[1] http://www.cdpr.ca.gov/

There are gaps in the DPR land area/crop choice data because: 1) DPR did not query data from some areas, and 2) some crops were grown without pesticide application. For these reasons, we also used data from the CAC to create the foundation datasets for delineating production areas. Thus, we collected CAC historical data for all the available crops at the county-level during five years (2004-08) and we used their average to help provide missing data in the DPR records. Together these sources provide a record of most of the crops planted in the state and their location. This information embodies actual crop choices made by growers throughout the state over that time period. Crop choice integrates the actual constraints faced by individual farmers when deciding what to plant, including water availability, crop costs and prices, agroecological limitations and opportunities, and numerous other factors, small and large, which affect crop choice.

To identify the cropping systems used in California, the cropping patterns of five different production regions were analyzed. These five production regions defined in this research are: Sacramento Valley (SAC); Northern San Joaquin Valley (NSJ); Southern San Joaquin Valley (SSJ); Southern California (SCA), including Imperial, Riverside, and San Diego County , (principally the Imperial Valley and Palo Verde Valley) ; and Coastal California, (COA) primarily the Ventura-Oxnard region, Santa Maria, and Salinas-Pajaro River Valleys (Figure 1).

Figure 1: Study area- the geographical subsets of California.



Data Source and Method

The data used for cropping pattern analysis are extracted from The California Department of Pesticide Regulation's pesticide use reporting (PUR)). We account for a group of major annual and short-term perennial crops in California, which includes: alfalfa, barley, broccoli, beans, broccoli, carrot, corn, cotton, forage-fodder, grasses, garlic, lettuce, melons, oat, onion, potato, rice, safflower, sorghum, sudangrass, sugarbeet, tomato and wheat. Land planted to trees and vines is not subject to short-term rotation and was not considered suitable for rotation with biofuel and bioenergy feedstock crops, so is excluded here.

We extracted cropping frequency data from 2003 to 2012 and analyzed the data using ordination and cluster methods. We performed non-metric multidimensional scaling (NMDS) in R[2] for the 5 major subsets of the data to identify the dimensions resulting in a reasonable representation of the regions studied. A matrix of crop frequencies by section was created and a K-means algorithm was applied for cluster analysis that grouped the sections in each subset based on the cropping frequency. Regional clusters are considered to be representative cropping systems when used for the BCAM model (see below). Clusters may not be physically contiguous, but reflect similarities in land use for crops within larger agricultural production regions. These similarities may be based upon a diverse set of biophysical and economic factors, which are more or less strongly correlated with crop choices by growers (Yang et al., in prep). Collectively, however, they result in a similarly effective set of constraints on crop choice.

Table 3 to Table 7 present the cropping systems which are identified in this analysis. For each cluster in each region, the yearly average acreage-planted of each crop type is also queried from PUR.

Table 3: Observed cropping pattern in Sacramento Valley measured in acres (2003-2012 data)

Crop	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7	Cluster 8
Alfalfa	3404	77522	2098	12847	2130	2539	16678	70362
Barley	436	900	82	2263	319	1195	274	177
Beans	6101	2507	4942	2460	1054	1350	977	5514
Broccoli	70	31	11	33	13	472	11	212
Carrot	323	79	131	87	21	26	66	223
Corn	10589	30054	3275	6718	3267	48959	2987	17049
Cotton	774	1049	1082	432	1091	607	390	294
Foragefodder	249	2469	100	2164	694	1474	609	417
Garlic	495	147		106	90	79	48	298
Lettuce	1	7	15	932				60
Melon	4176	644	3266	691	680	476	765	2047
Oat	1013	8278	165	6357	829	8460	1193	3251
Potato	513	315	101	334		1903	178	283
Rice	2295	917	37827	11047	524675	796	38111	651
Safflower	2259	3278	2577	1396	1140	1042	834	4138
Sorghum	368	2968	130	588	241	494	394	969
Sudangrass	162.83	1721	98	688	198	1834.62	66	415
Sugarbeet		146		90		160		100
Tomato	45529	3773	11094	5532	6220	1935.51	2633	50678
Wheat	21038	17220	9883	19686	3766	5459	7957	32692

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[2] (The R foundation for Statistical Computing 2005)

For the Northern California regions (predominantly the Sacramento Valley), Figure 2 reflects the location of the resulting clusters. Additional maps are reported in Appendix A.

Figure 2: Northern California region and crop clusters used as representative cropping systems. See Appendix A for details and maps for other regions.

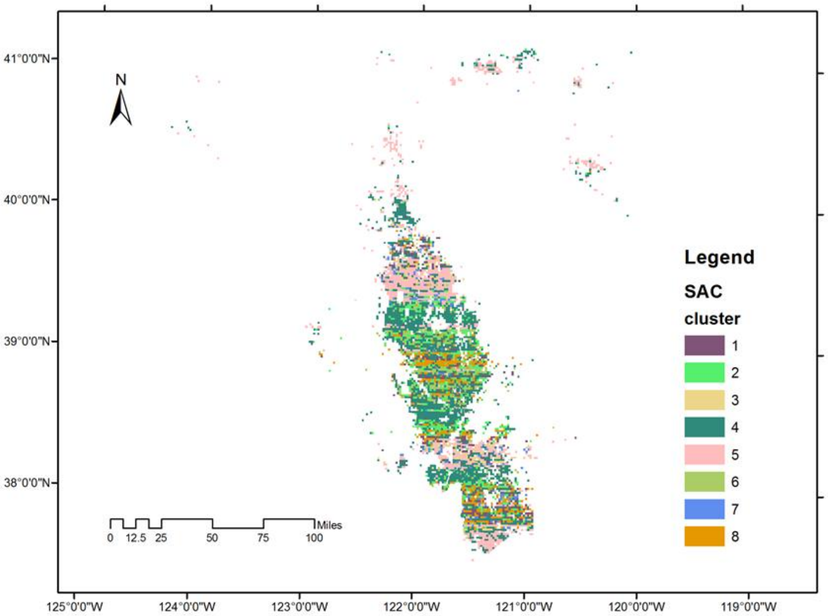

Table 4: Observed cropping pattern in Northern San Joaquin Valley measured in acres (2003-2012 data)

Crop	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Alfalfa	5301	97598	82346	24494
Barley	2496	2620	750	5130
Beans	5127	2345	5569	9803
Broccoli	2006	314	471	4742
Carrot	362	429	166	705
Corn	4517	28273	132820	20179
Cotton	113234	98671	4429	21356
Foragefodder	137	216	1471	573
Garlic	17962	535		1313
Lettuce	14308	590	83	3654
Melon	4638	1383	466	3142
Oat	502	5441	47958	13843
Potato		99	3079	4484
Rice	1081	2298	784	3648
Safflower	3572	640	115	882
Sorghum	286	234	420	402
Sudangrass	131	533	1126	410
Sugarbeet	4017	8539	1768	2111
Tomato	100147	29921	4875	19132
Wheat	26890	19927	25856	25529

Table 5: Observed cropping pattern in Southern San Joaquin Valley measured in acres (2003-2012 data)

Crop	Cluster 1	Cluster 2
Alfalfa	63370	143463
Barley	2896	1338
Beans	3327	3129
Broccoli	770	978
Carrot	32530	2990
Corn	14245	171727
Cotton	175574	85276
Foragefodder	389	262
Garlic	6849	765
Lettuce	2051	183
Melon	3106	417
Oat	10679	5769
Potato	22123	938
Safflower	15310	690
Sorghum	3972	9534
Sudangrass	1107	751
Sugarbeet	1804	2378
Tomato	38942	3081
Wheat	73298	132089

Table 6: Observed cropping pattern in Coastal California measured in acres (2003-2012 data).

Crop	Cluster 1	Cluster 2
Alfalfa	5771	1052
Barley	7116	509
Beans	3932	5506
Broccoli	18016	91630
Carrot	7307	3745
Corn	13504	12458
Foragefodder	1674	49
Garlic	986	5682
Lettuce	11139	171933
Melon	36	30
Oat	9145	3412
Potato	2311	269
Safflower	323	25
Sorghum	283	493
Sudangrass	125	34
Sugarbeet	121	724
Tomato	29548	31473
Wheat	3618	750

Table 7: Observed cropping pattern in Southern California measured in acres (2003-2012 data).

Crop	Cluster 1	Cluster 2	Cluster 3
Alfalfa	70864	8081	159684
Barley	57	398	207
Beans	80	707	102
Broccoli	8921	2656	3457
Carrot	15001	4479	3298
Corn	6412	3999	4578
Cotton	2534	1318	17285
Foragefodder	414	510	2580
Garlic	117	157	289
Lettuce	32588	6087	2445
Melon	3315	1989	1976
Oat	350	1124	1329
Potato	1442	4481	514
Rice		20	
Safflower	5	786	
Sorghum	66	446	945
Sudangrass	2093	730	3031
Sugarbeet	9344	1433	37062
Tomato	188	518	71
Wheat	19588	13491	30188

Land Use Change Issues Unique to California

The factors included or left out of LCA calculations can lead to strikingly different assessments about the value of biofuels (Plevin at al., 2013). Similarly, the boundaries assumed for the calculation of life-cycle effects also influence results. Another critical factor is the discount rate assumed to apply to damage from GHG emissions from biofuel production (USEPA, 2009; CARB, 2009). Most initial calculations about the GHG reduction benefits of biofuels were based on estimates at the field boundary and the fuel manufactured from those fields. But Searchinger et al. (2008) argued that previous LCA calculations showing positive GHG effects from the use of crop-based biofuels (Farrell et al, 2006) become significantly negative if indirect effects related to land conversion are considered. Stated briefly, Searchinger et al.'s hypothesis was that using staple commodities like corn or soybeans for biofuels in one part of the world will lead to an increased use of land in other parts of the world to replace the lost food crops. Converting forest land to farm land in places like Brazil may release such large amounts of carbon from vegetation and soil organic matter (SOM) to the atmosphere that the positive effects of crop-based biofuel use on GHG reduction are reversed. In effect, they argued that it is essential to broaden the boundary conditions of LCA calculations about biofuel crop production beyond the field-scale to include the entire worldwide system of agricultural markets and use the global atmosphere as the system boundary. They estimated that the use of corn ethanol would result in a net increase of 104 g CO_{2eq} per MJ of ethanol. This change resulted from including carbon loss from land conversion in remote regions, called market-mediated effects or indirect land use change (ILUC). More recently, Liska et al. (2014), have challenged the reputed benefits of using corn stover as a biofuel feedstock asserting that its use reduces the storage of carbon in soils resulting from its in situ decomposition.

Adopting this argument, but using a more appropriate set of methods, staff at CARB reduced Searchinger, et al.'s (2008) estimate of ILUC carbon losses substantially to 30 g CO_{2eq} per MJ (CARB, 2009). In 2014, CARB proposed a yet lower value of 24 g CO_{2eq} per MJ. Other recent estimates lower it further (Tahriapour and Tyner, 2009). Adding that value to CARB's estimate for the generic life cycle CO_{2eq} costs for corn ethanol, however, makes average corn ethanol nearly equivalent to gasoline in its GHG effects on the atmosphere, rendering it useless in helping fuel blenders to meet the LCFS 2020 goal of 10 % lower GHG emissions from transportation fuels, so long as the amount of ethanol in gasoline is limited to 10%. The use of cropland is the key issue. Any crop based biofuel will be assessed with additional carbon GHG costs. The federal RFS specifically allows for corn ethanol use (USEPA, 2009), but most corn ethanol eventually will not be of use in California because of the different regulatory standard used.

CARB uses the Global Trade Analysis Project[3] (GTAP) model to assess the indirect or market-mediated effects of corn ethanol and other crop-based biofuels. The GTAP model, a Computable Global Equilibrium (CGE) model developed at Purdue University, is used in California's LCFS to estimate this indirect carbon cost by inferring land-use change elsewhere in the United States and internationally. GTAP uses data on land values and crop production from around the world, together with estimates of most significant international economic sectors, to analyze world food markets subjected to pressure from the use of corn for ethanol in the United States, or other crop uses for fuel. All other factors are held constant. One of the mechanisms for market adjustment required by the model structurally when crop production in the United States or elsewhere is altered is change in land allocated for crop production. These estimates of land use inferred from the GTAP CGE model are combined with estimates of the carbon content of terrestrial biomass and soil carbon on affected acres to estimate carbon losses from changes in land use. The attribution of indirect effects has not been attempted in any regulatory mechanism before the LCFS and RFS and is difficult to apply. The EU to date has refrained from adopting ILUC values in its alternative fuel regulations.

The use of GTAP for this purpose has been criticized. Critics state that the decision to use GTAP to infer ILUC effects was identical to a decision to bias the LCFS against crop-based biofuels, that the model is being used inappropriately and does not accurately estimate ILUC in the real world, (Liska and Perin, 2009; Kline et al., 2009; Babcock, 2009), that it does not account for new technologies and is unbalanced in its treatment of them (Kim et al., 2009), that it fails to predict accurately even induced land-use change in the United States (Babcock, 2009; Glauber, 2009; Mueller et al., 2009), and that it is poor policy for agencies to pick preferred technologies rather

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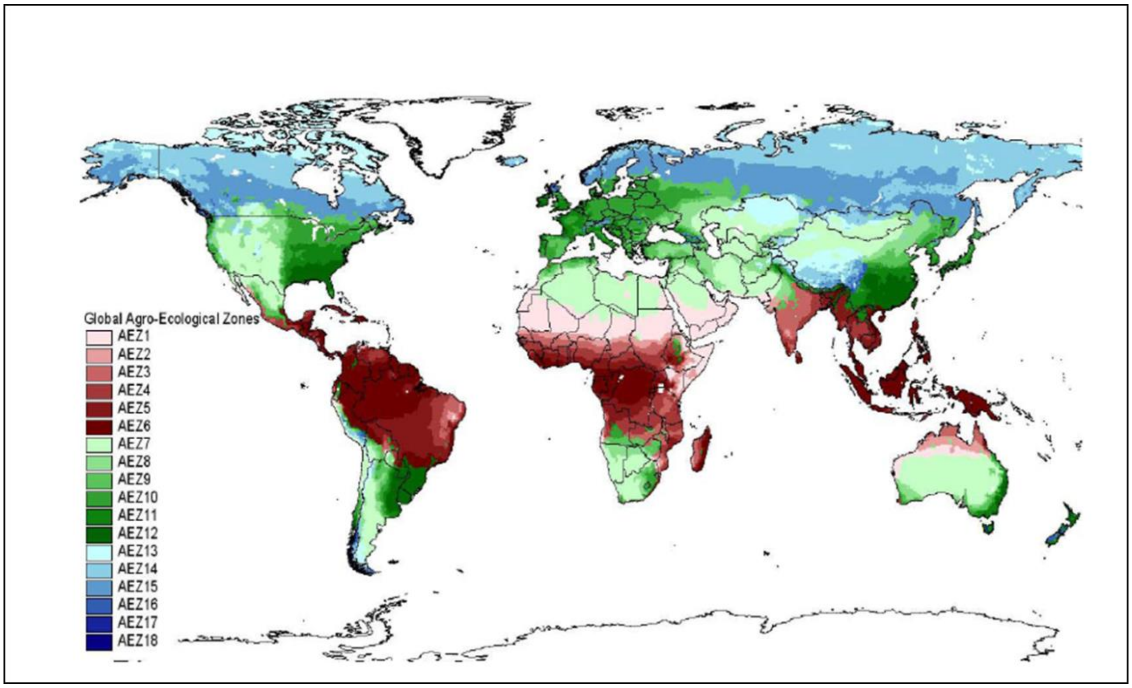
[3] https://www.gtap.agecon.purdue.edu/default.asp

than allow the best fuels to emerge over time, especially at early stages in the development of biomass-based fuels. Additional problems arise with the interpretation of land use, in this case especially in California. A record of this debate is available at the CARB website[4].

In part in response, GTAP has been modified to more accurately address some of these criticisms and improve its estimates of land changes (Tyner et al., 2012). One important change has been the adoption of agroecological zones (AEZs) that much more accurately reflect land use by climate and region around the world than was done in earlier versions (Figure 3, Table 8). Data includes AEZ specific terrestrial carbon stocks, more regionalized crop yields and land rent costs, among others.

Figure 3: The SAGE (http://www.sage.wisc.edu/) global map of 18 acroecological zones (AEZs). California as a whole is included in AEZs 9/10 and AEZ 27.

From https://www.gtap.agecon.purdue.edu/resources/download/2375.pdf



The characteristics of these AEZs are described in Table 8. California seems to be classified as AEZ 9/10, a temperate, moist semi-arid region with a growing season on 120 to 179 days and a temperate, sub-humid region with a growing season of 180 to 239 days. In fact, California is predominantly a Mediterranean (winter rainfall, summer dry) to semi-arid region, with a 365 day growing season. Similarly, the Imperial Valley and Palo Verde Valley have 365 day growing seasons, for which there is no correspondence in Table 8. There is no separate AEZ category for irrigated lands, further limiting the value of these AEZs for analyzing effects within California.

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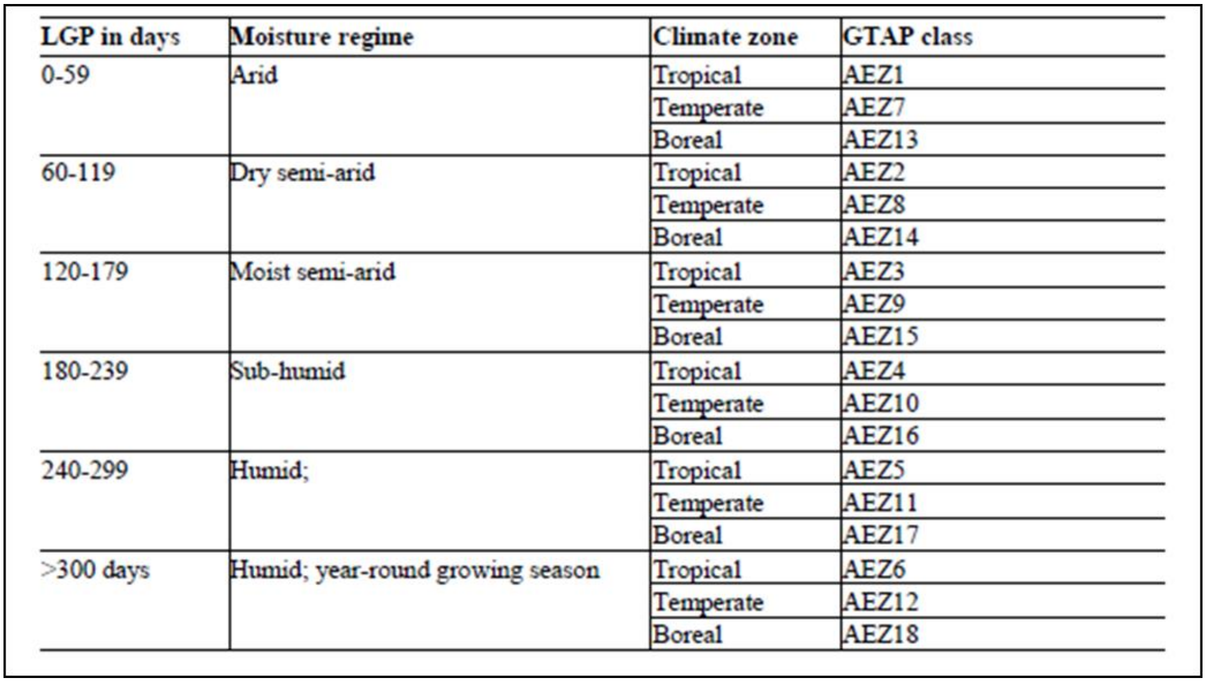
[4] http://www.arb.ca.gov/fuels/lcfs/lcfscomm.htm

Crop productivity is modeled as a standard C4 crop (corn) and generic C3 crop. For areas like the American mid-west with large regions with similar cropping patterns and simplified crop rotations (often corn-soybean), this level of representation is useful. But it is a highly simplified representation of California's many, highly diverse crops and regions.

Models used to operate at the national and world scale lack sufficient detail to accurately reflect the complex, exceedingly diverse character of California's agriculture. The BCAM model was created to more accurately reflect this complicated land use system and better estimate crop displacement and changes in farmland use. Estimates of total land and the individual crops displaced for the potential bioenergy crops evaluated here are provided here. Crops like dry beans, Bermuda grass and Sudan grass hay, are not included in the models used in California by CARB, and poorly characterized, in our view, in the models used by US EPA. The fact that new crops or additional acres of incumbent crops may be brought into production when crops are adopted is not accounted, and the effects on fallow land or fallow periods during the multi-year operation of many of the state's complex cropping systems also is not accounted in state and federal modeling efforts. Widespread farming and crop rotation practices in California continuously support new crop adoption opportunities in the state's agricultural systems (for any purpose. This results in more efficient total resource use when new crops are adopted. A history of compensatory yield increases among many crops also contributes to the conclusion that in-state feedstock production is likely to have small to no market-based effects within or outside the state. This should give in-state producers an opportunity to be lower CI feedstock producers, compared to others who rely on common agricultural commodities and locations and derive their feedstocks from markets with well-developed trade channels.

Table 8: Definition of global acroecological zones used in GTAP.

https://www.gtap.agecon.purdue.edu/resources/download/2375.pdf



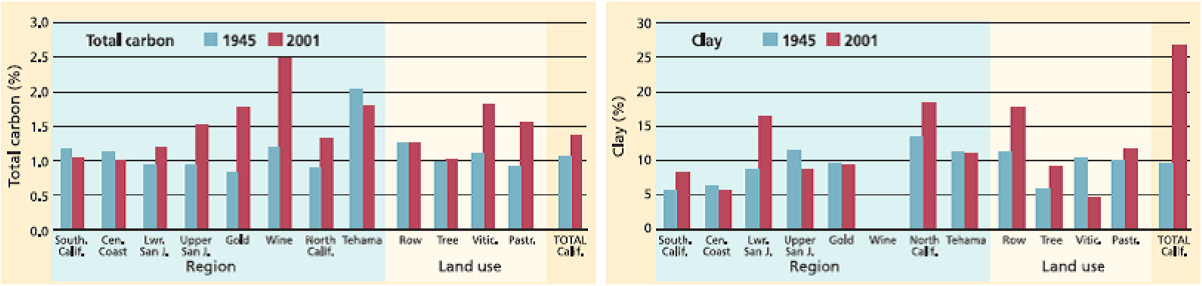
LGP in days	Moisture regime	Climate zone	GTAP class
0-59	Arid	Tropical	AEZ1
		Temperate	AEZ7
		Boreal	AEZ13
60-119	Dry semi-arid	Tropical	AEZ2
		Temperate	AEZ8
		Boreal	AEZ14
120-179	Moist semi-arid	Tropical	AEZ3
		Temperate	AEZ9
		Boreal	AEZ15
180-239	Sub-humid	Tropical	AEZ4
		Temperate	AEZ10
		Boreal	AEZ16
240-299	Humid;	Tropical	AEZ5
		Temperate	AEZ11
		Boreal	AEZ17
>300 days	Humid; year-round growing season	Tropical	AEZ6
		Temperate	AEZ12
		Boreal	AEZ18

Similarly, values for soil organic matter content and assumptions about changes in stocks assumed for this AEZ analysis may not reflect the circumstances of farming in California. Soil organic matter (SOM) contributes to soil fertility, aggregate stability, and resistance to erosion (Seybold et al. 1998). For the most part, alternating annual and short-term perennial crops in rotation results in little change in soil carbon behavior in California soils. Soils in annual cropping systems in California are low in SOM compared to temperate agricultural regions. It is difficult to increase SOM under farming conditions in California, and slowly, intentionally accumulated increases established over a period of years are easily reversed in a matter of months if not sustained, and can occur with a change in cropping patterns or tillage practices. Nor is it clear that efforts to increase SOM are always beneficial in measureable ways. Results from long term research suggest mixed outcomes in cropping systems in California due to the presence of increased SOM (Kaffka et al., 2005).

Alternatively, some of the feedstock crops analyzed here may be suitable for reduced tillage or no-till systems, which may increase SOM under California conditions (Suddick et al., 2010). Energy beets, canola and Camelina and grain and sweet sorghum all are possible candidates for reduced tillage systems. Sugarcane, energy cane, and Bermuda grass are perennials. To the degree they displace annual crops, they provide the opportunity to increase SOM or other remediation benefits. In the case of Bermuda grass, reclamation of salt-affected soils has been documented (Corwin, 2012). Perennial crops also reduce erosion relative to annual ones since they retain cover year round.

Empirical evidence suggests that SOM is largely maintained at a steady level based on conventional farming practices in California. DeClerq and Singer (2003) carried out novel and unique research to evaluate long-term changes in soil quality over time in California by comparing soil quality characteristics in archived soil samples with samples from the same locations collected for their study in 2001. Different sets of archived samples were collected in 1945 and over a number of years before 1959. Soils from tree crop, viticulture, row crop and rangeland sites were compared. They analyzed soil pH, salinity (as ECe), P, total N, organic matter, and soil texture (sand, silt and clay). A number of measures changed in ways that suggest improvement in soil quality (plant-available P, total N, and organic matter increased with time, soil salinity declined with time, pH remained stable). On the adverse side, soil clay content increased, which the authors interpret as a sign of soil erosion over the 50 year period (Figure 4). Overall they concluded that most of the properties measured representing soil fertility changed positively, including SOM. Increased clay percentages indicated some erosion of more transportable silt and sand particles, but overall they concluded that farmed soils in California have maintained their chemical and physical quality over the 50 to 60 year period during which agriculture intensified. This evidence, combined with increasing crop yields and efficiency in crop production (Kaffka, 2009), suggests that the soil resource is being conserved and maintained in ways that serve the public interest in sustaining agricultural productivity over time.

Figure 4: Changes in SOM and soil clay content by types and location. From DeClerq and Singer (2003).



There are other types of issues unique to California that are difficult to include or interpret with GTAP. Besides responding to economic factors, land use in California also responds to variation in rainfall patterns, especially drought, and to legal developments affecting the operation of the state's and the federal water infrastructure projects. For example, in 2014 due to regulatory policies and drought, nearly five hundred thousand acres of farmland are idle in California, particularly in the San Joaquin Valley. California is subject to periodic droughts. Especially in recent years, these droughts have resulted in reduced irrigation water deliveries to agriculture, especially south of the Delta. In addition, environmental litigation sometimes has affected water deliveries for farming and other uses. As a consequence, farmers idle some of their land, especially land used for annual and short-term perennial crops. This is equivalent to the land evaluated here for biofuel feedstock production. A recent estimate is that at least 410,000 acres in California's central valley will receive no irrigation water this year, and other acres will be under-irrigated[5]. Additional emergency curtailments of surface water rights are occurring and were not accounted fully at the time of this report. But fallowing of productive land has been occurring for several years due to policy and drought influences, so current year estimates are underestimates of the full land use effects occurring.

Idling of this land, logically, has effects on land use elsewhere in ways similar to those if it had it been used for biofuel feedstock production, because it has been withdrawn from food production just the same. In future years, if water supplies again become available, the economic effects of forced fallowing of California farmland, if any, will already have been integrated into global markets. This creates challenging regulatory considerations. If that land were to be brought back into production once irrigation water becomes available, would its use for biofuel feedstock be assessed for market effects and putative indirect land use changes that may have already occurred when it was first idled? For example, USEPA discounts land use effects from the production of Camelina in the Pacific Northwest on lands they assert otherwise would have been fallow or used less intensively (EPA, 2013). The principle is the same.

Collectively, these dynamic, changing land use patterns make it difficult in California to determine what constitutes a baseline for land use. The regional cropping systems identified in our analysis and used to test crop adoption thresholds reflect longer term average behavior. But these patterns depend on the assumption that water will be available in the future at levels similar to the past. This may not be a reliable assumption. Nonetheless, actual crop displacement is likely far more subject to water supplies and natural and political factors affecting water supply than actual crop competition.

Additionally, changing land use is subject to economic forces and decisions made elsewhere in the world, some of which are political in character. The decline in the production of cotton in California is an example of these influences (Figure 6). At one time, more than 1.5 million acres of land were used for cotton, a non-food, industrial crop. For example, China imports GMO soybeans from South America, but uses GMO issues to restrict corn imports from the US, preferring instead to pay Chinese farmers corn prices more than two times the current US price. This is not an economic decision, but could have effects on land use that resemble the ones predicted in GTAP for corn use for biofuels. Another example is the substantial increase in meat production (primarily pork) that occurred in China over the last decade. Consumption increased at a much greater rate than growth in GDP, unlike in other world markets, signifying the essentially political character of the market (Figure 5a). Similarly, recent political decisions in China to increase dairy product consumption starting in about 2008, have consequences for the value of such products in domestic markets and influence land management decisions around the world, including California (Figure 5b).

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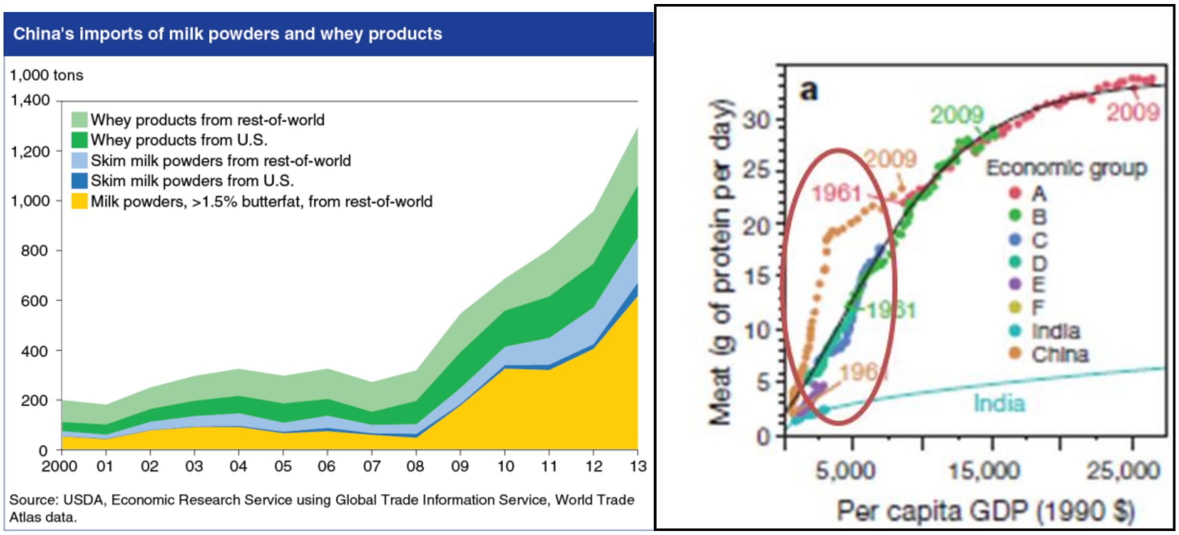
[5] http://www.nytimes.com/2014/04/21/business/energy-environment/californias-thirsting-farmland.html?src=twr

Figure 5: a) Increasing demand in China for imported dairy products has become a major driver in global markets, especially for milk powders and whey products. (USDA-ERS). http://www.ers.usda.gov/data-products/chart-gallery/detail.aspx?cahrtId=49507&ref=collection. b) China's exceptional growth in meat consumption was based on a political decision to increase consumption at a high rate, not strictly market forces. "China…had meat demand increase more rapidly with income than other groups, but was similar…by 2009." Tilman and Clark, 2014.



Evaluating ILUC for cropland in California is made all the more difficult by the fact that the GTAP model does not currently include California's farmland and specialty crops in sufficient detail in its estimates of market-mediated effects. A small amount of land allocation to industrial crops in California is a case of business as usual. Similarly, a significant area of land in California is devoted to grapes to support wine production. Most people do not regard wine as food, so society condones the use of scarce land and water and other resources for non-food purposes. As a consequence, there is little reason to consider that at the modest levels of biofuel feedstock adoption considered likely here, there is any reason to regard such adoption as having significant or predictable effects on land change elsewhere in the world. For example, in a recent, comprehensive, empirical analysis, Persson et al., (2014), summarize the effects of agricultural production on the world's tropical forests, the most at-risk, biotically valuable, and carbon rich ecosystems in the world. They found that national and international trade in beef, soybeans, palm oil and wood products are the major drivers of deforestation worldwide in these ecosystems. More importantly for the discussion of land use effects from crop substitution in California and the US in general, they find that land use in the US has practically no effect on these processes. On the contrary, crop exports from the US tend to reduce GHG effects from land use change in general[6]. This view of US crop production conflicts with the understanding

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[6] "It should be noted that the US does not appear (to be) a major consumer country in our analysis, as they produce significant quantities of beef and soy commodities and thus are an important supplier of deforestation-free commodities to the world market." Persson et al., 2014.

derived by regulators from the use of models such as GTAP, but lends additional support to the conclusion that GHG effects associated with ILUC for in-state production of bioenergy crops at the scale estimated to be likely here are largely close to zero. Additional support comes from a recent analysis by Babcock and Iqbal (2014), who argued that the methods used by CARB for ILUC significantly overestimate ILUC values. If true, then ILUC estimates for in-state feedstocks will have very low values, and can be considered to be zero as default values.

Figure 6: Idled farmland in the San Joaquin Valley of California (2014). Photo: NY Times

Changes in Annual Field Crop Acres in California Changing Land Use Patterns

Crop shifting is common in California

Farmers follow no rigid crop rotation pattern for the most part in California, though crops occur in recognizable regional patterns, as discussed. California is not an important commodity export source except for rice and specialty crops. In most cases these are non-essential foods or products like wine. Nationally, there exist strong social movements to increase local production (including year-round) of many horticultural crops closer to where they are consumed rather than relying on distant California as a source. These and many other social and market related factors are changing constantly, making it difficult to assert cause and effect for changing uses of land. A significant land use change in California for arable land use has been the decline in cotton production, due to both price and policy issues. Other changes in land allocation of important crops affected by biofuel feedstock production are reported in Figure 7 to Figure 12. Increased demand, especially in Asia, for nut crops has driven large-scale conversion of land from annual crops to trees. Similar processes affect planting of grapes for wine.

Figure 7: Changes in corn acres in California. There has been a shift from corn grain production to corn silage production to support dairy systems.

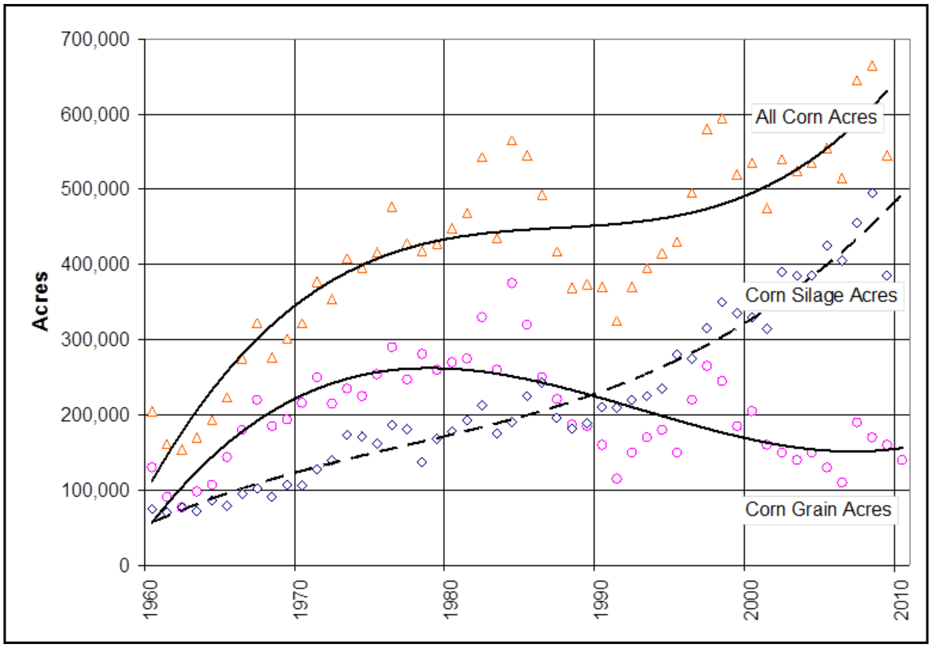


Figure 8: Changes in cotton acres in California. Cotton acres in California have declined since the 1980s due to international market forces. Cotton, an industrial crop, once dominated land use in the San Joaquin Valley.

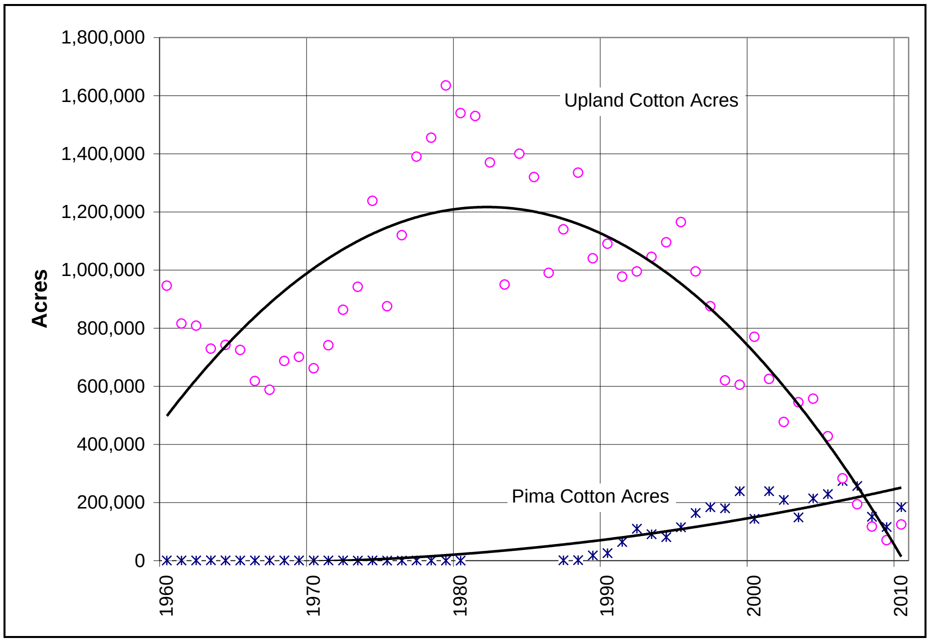


Figure 9: Changes in wheat in California. Wheat acres have declined from historic highs since the 1980s but have remained stead at about 400,000 acres since that time. Some of these acres are from non-irrigated (dry-farmed) fields in coastal and valley foothills

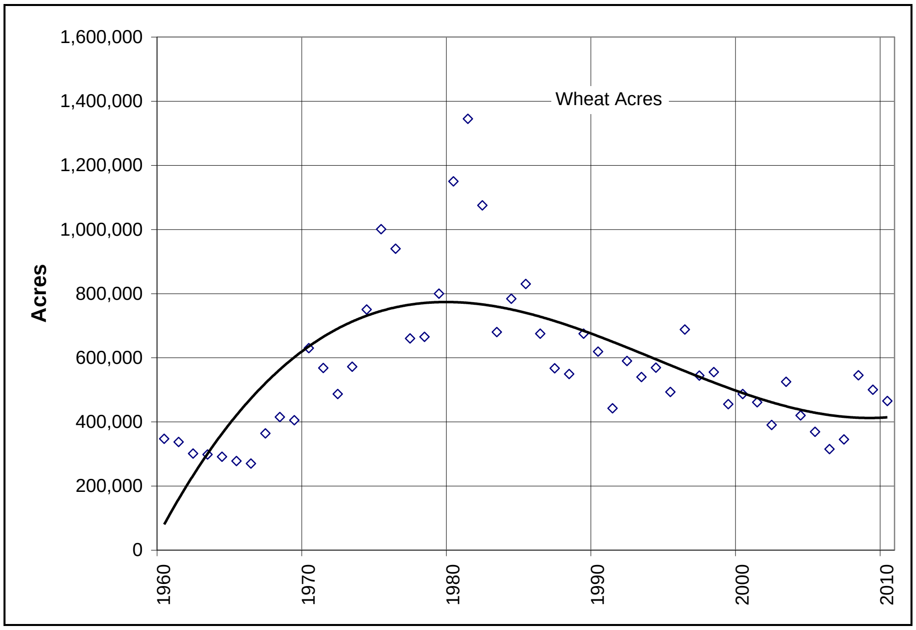


Figure 10: Changes in dry bean acres have declined in California. As a summer crop, they require and use water less efficiently than winter crops like wheat, canola, and Camelina.

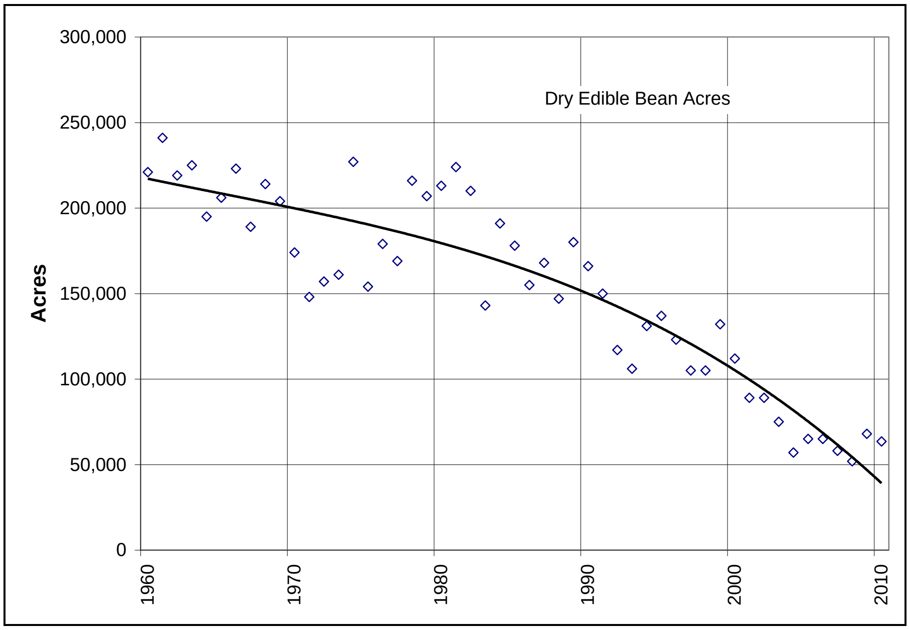


Figure 11: Changes in land allocation by crop type in California. Non-cultivated lands are devoted to trees and vines, primarily. (USDA/NRCS, 2009)

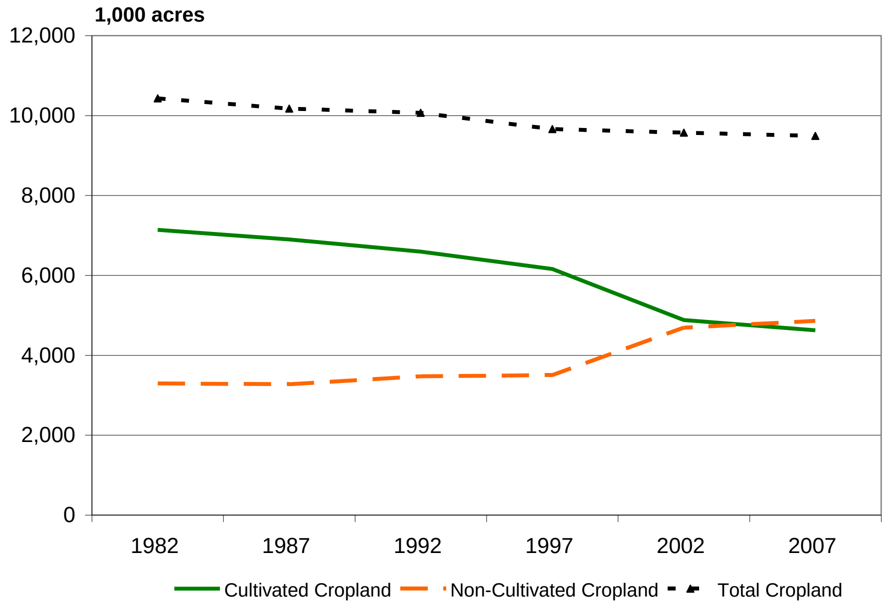
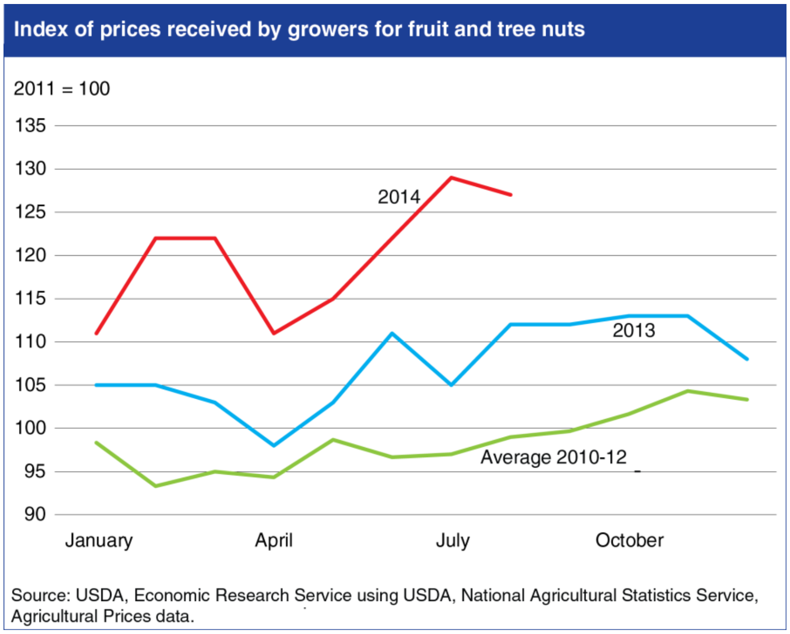


Figure 12: Changes in land use are responding to increasing prices for nut and tree fruit crops.

The index of prices received by U.S. fruit and tree nut growers has remained consistently above year-ago levels and 2010-12 average levels during 2014. The August grower price index for fruit and tree nuts was up 13 percent from a year earlier and 28 percent above the 2010-12 average. http://www.ers.usda.gov/data-products/chart-gallery/detail.aspx?chartId=49367&ref=collection

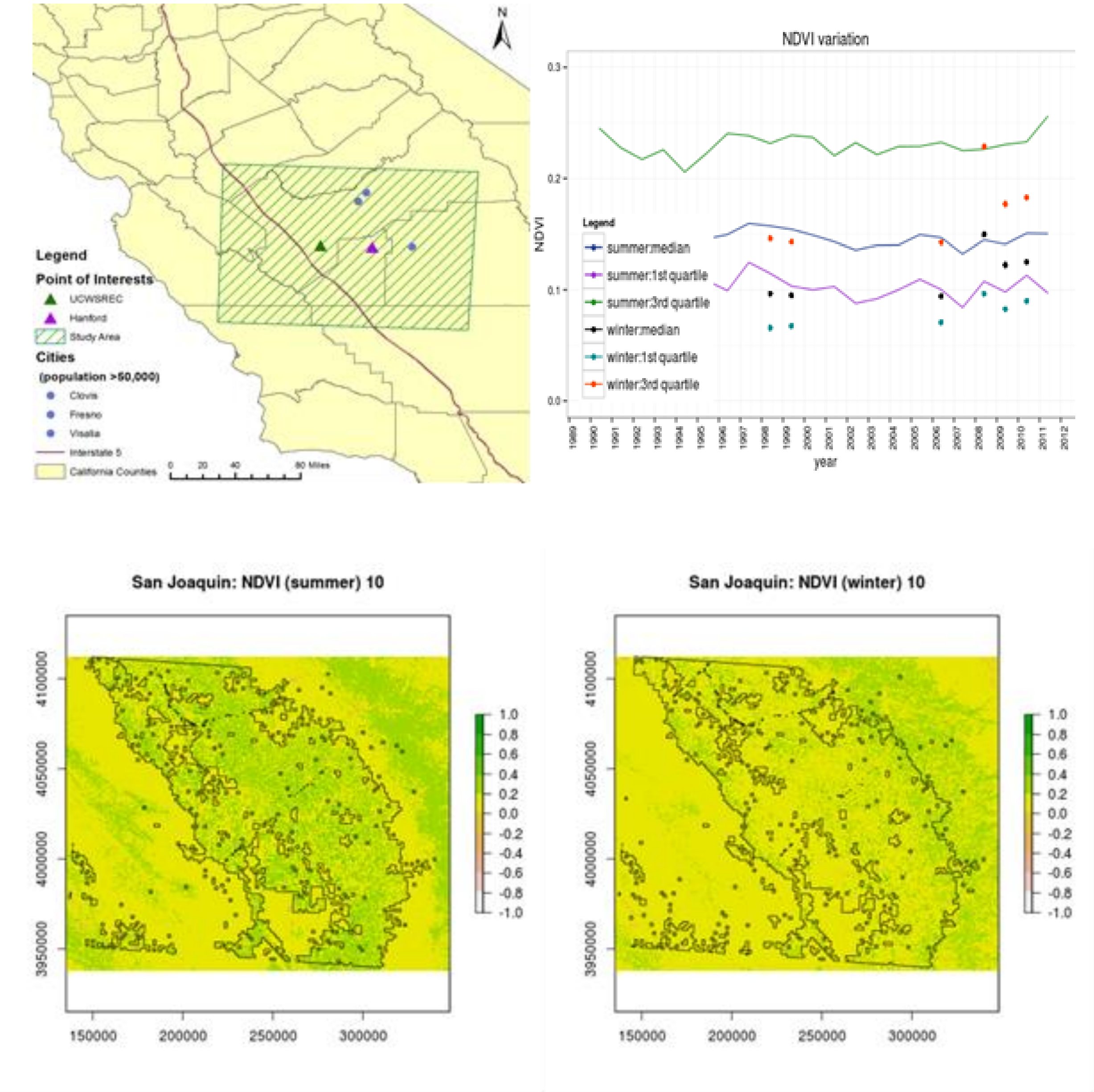


Source: USDA, Economic Research Service using USDA, National Agricultural Statistics Service, Agricultural Prices data.

Another common pattern observed in California agriculture is the tendency for reduced land use in winter periods compared to summer, despite a year-round growing season (Figure 13). This is due to fewer crop choices in winter and higher levels of productivity during summer's longer days. Nonetheless, there is opportunity to more fully utilize slack production periods in winter in the Central Valley with crops like winter annual oilseeds and energy beets, for example. DeCiccio (2013) has argued that to be useful as a strategy, bioenergy crops must absorb additional CO_2 from the atmosphere, compared to current, average levels of atmospheric removal by crops, pastures and forests. Increased use of slack periods in crop rotations, and enhanced overall RUE at both the crop and cropping system level address to a significant extent the carbon accounting issue raised by DeCiccio.

Figure 13: Inter-annual variations of summer/winter Normalized Difference Vegetation Index (NDVI) derived from Landsat images in San Joaquin Valley region.

a) The study area is defined as the jointed 50-mile buffer area from Hanford and UCWSREC; b) Lines indicates the median NDVI values during summer period fluctuating among years, and points indicate lower NDVI values during selected winters (winter images are not available in most years due to ground fog; c) and d) NDVI map in 2010 overlapped with cropping area derived from California Pesticide Use Report (PUR) data. Source: NASA Landsat Program, 2013, Landsat TM+



3. Economic assessment of the potential for purpose-grown biofuel crops and biofuel production in California (BCAM)

Crop substitution must be estimated to evaluate land use change using CGE models in the way chosen by CARB for the LCFS. This is done here using the BCAM model. The BCAM model is a multi-region, multi-input and multi-output model, which uses PMP optimization principles. PMP methods, estimate the parameters of the production functions of each incumbent crop using the shadow prices of inputs in the base system, which can be defined as the maximum price that farmers are willing to pay for an extra unit of inputs (i.e. land or water) for producing a crop *i*. The PMP model then transforms these opportunity costs into parameters of a quadratic production function that preserves the core relationship information within the system as new crops are introduced. This allows the land area values for each crop to vary with a change in price, while holding the marginal values of the base system constant. In addition the additional PMP curvature adds flexibility to the traditional linear objective function avoiding overspecialization (i.e. to allocate all the resources to produce only one crop –the most profitable one) (Howitt 1995). In other words, the BCAM model used a PMP optimization approach to calibrate against the existing cropping system in order to obtain some parameters that would help to recover the marginal input costs from the observed average costs of those inputs. The yields of the incumbent crops are substituted with the PMP derived quadratic production function. New crop alternatives are tested by holding the non-linear coefficients of the existing cropping system constant while incrementally increasing the profit for the exogenous energy crops, which enter in the model as a linear equation. Exogenous energy crops are not part of the initial system and have no opportunity cost constraint. The model structure allows the output price and the input costs to be varied. Once the PMP coefficients were established, incremental changes in profit of the new (exogenous) energy crop was optimized by adjusting the energy crop output price over a range of price increases at specified, regular increments.

It is common in bioenergy supply and demand discussions to focus on changes in biomass yield, output price, and input costs. However, in BCAM profit was maximized instead. Profit is a composite function of those three factors. The solution represents a marginal profit level that acts like a long run incentive, similar to a production contract price. Thus in the BCAM model, the results are generated as profit; however, it is possible to work backwards from the profit to infer other variables (price, yield or cost per acre) by keeping constant two of them and solving for the third. In this case the BCAM model generates a profit. The underlying price can be identified at the cluster level, keeping yield and input costs constant.

Storage and transportation costs to the processing facility are not included here. Also model outputs rely on existing technology and production practices as a foundation for examining the adoption of the new crop. Therefore, any new cropping pattern generated by the model, if different from the current pattern, will only be adopted if it is more profitable than the observed pattern of crops that was identified using farmers' prior crop adoption and production behavior.

Budgets that include the costs of production, land rent and fixed costs for all the crops present in different locations in the state are required for the model. Crop budgets for the BCAM model are derived from several sources discussed in Appendix B. Budgets are based on information about costs acquired over several years, but were adjusted here to 2012 price levels.

For economic information about crop production of the incumbent crops, we used a set of enterprise crop budgets obtained from Cost and Return Studies published by the Department of Agricultural and Resource Economics at UC Davis[7]. These budgets were derived from a combination of sources, including growers' reports, observations by UCCE extension advisors in each county, and literature sources. They have been developed over a multi-year period and vary in what is reported. To be used for simultaneous comparisons, they must be adjusted to reflect a consistent format and timeframe. Then, these diverse budgets were adjusted for price levels using 2012 as a base year by using the Consumer Price Index. In the case of the data for new bioenergy crops being evaluated that had little or no prior production history (i.e. sweet sorghum, canola and sugarcane) different sources of information were used. For the cost of production of sweet sorghum, we used a silage sorghum enterprise budget from the UC-Davis C&SR as a proxy. We updated this sweet sorghum budget using 2012 prices. Information on the cost of production of sugarcane in the Imperial Valley (also used for energy cane), discussions were held with growers with experience producing the crop.

The BCAM model is conservative in that only 90 to 95% of conventional land use is represented as the land use pattern within each cluster. Once the number of crops in each cluster was determined, the prominent crops were rescaled so that the primary crops summed to 100 percent. This is to make modeling more tractable since some crops occur infrequently and commonly are planted in response to short-term market signals affecting price. This makes results here conservative since 5% of California's irrigated land is approximately equivalent to 400,000 to 500,000 acres, equal to the amount of land likely to be used for bioenergy crops estimated below. It is important to emphasize that in this project we conducted an equilibrium analysis. What was needed for this purpose are those crops that accurately represent the consistent, recurring crop choice decisions of farmers in California. The 5 percent of land that is not included represent those marginal or occasional crops that change constantly, which do not reflect the long-term equilibrium of the system. It is also important to note that this same amount of land is highly subject to change as a characteristic of farming strategies and conditions in California and is not unique to an economic environment where bioenergy crop adoption is possible. With low levels of adoption, land that is often idle or subject to change in that category may be sufficient in some areas to sustain a bioenergy enterprise without consequential effects on land use.

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[7] The UC Davis Cost and Returns Studies are available on this website: http://coststudies.ucdavis.edu/

Results

Canola

BCAM was calibrated using the observed cropping patterns in the SAC, NSJ, SSJ, and SCA California regions, as well as any reported production costs and yield information for each crop in each of these regions. The price of canola was then increased iteratively to simulate the effect of a continuous increase in the price of canola. This allows a determination of 1) the entry price in each of the four California regions; and 2) which incumbent crops are displaced. For canola, only one production cycle from November to June was modeled, which is consistent with the multi-year observations of crop performance (Kaffka et al., 2014). Yields were assumed (conservatively) to average around 1.25 t/ac with seed oil content of about 43.5 percent. However, actual yields can be much higher at times. For example, under favorable conditions, 2 tons/acre have been observed for superior varieties (Kaffka et al., 2014).

Results from several years of trials around the state of California indicate that there is a substantial range in yield potential for canola based on variety and location. The yield of canola and other crops affects both rate of adoption and the number of acres needed to meet different levels of in-state biofuel production (Table 9). The effects of canola yield increases on rate of adoption and in-state fuel production are evaluated as an example. At the highest yield levels frequently achieved in trials in California (1.75- 2 ton/acre of seed), the number of acres needed to approximately double in-state production of biofuels is 260K to 300K acres per year. This is less than current in-state production of wheat and approximately similar to current production of cotton. The table shows the acres of land needed for the production of canola to achieve 60 Mg/yr of in-state biodiesel production as the yield of canola (measured in terms of t/ac) varies.

Table 9: Acres of canola production needed to achieve 60 Mg/y of in-state biodiesel production.

Yield (t/ac)	Yield (lb/ac)	Oil %	Lb oil/ac	Gal biodiesel/ac	Ac needed for 60 Mg/y	Base price of canola $/t
1	2,000	0.425	850	116	515,294	720
1.25	2,500	0.425	1,063	146	412,235	576
1.5	3,000	0.425	1,275	175	343,529	480
1.75	3,500	0.425	1,488	204	294,454	411
2	4,000	0.425	1,700	233	257,647	360

The effects of canola yield variation are modeled here. First, the entry price of canola in each region as the yield of canola changes was examined. The base price of canola decreases as the yield of canola increases. Furthermore, as shown in Table 9, the total acres needed for the production of canola to achieve a total of 60 Mg of biodiesel/yr also decreases as the yield of canola increases. For a given yield of canola, the base price of canola (as shown in Table 9) is increased iteratively until canola is adopted. Based on these iterations, the entry price range for each region, defined as the minimum price in which canola first begin to appear in the agricultural system in these four regions, was determined. The regional entry prices ($/ton) and the number of acres adopted at these entry prices for canola production are shown in Table 10 through Table 13. While the SAC region consistently has the lowest entry price for canola production for canola yield between 1.25-2ton/acre, the SSJ region has the largest total acreage over the range of entry prices shown when canola yield is between 1.25-1.75 ton/acre (see Table 10 through Table 12). However, when canola yield is at 2 ton acre, the SAC region has the highest acres of land adopted for canola production, i.e. almost 10,000 acres, for a canola price range of $361-$366/ton.

Table 10: Regional entry price for canola (1.25 t/ac) and the number of acres adopted at each entry price.

Price of Canola ($/ton)	SAC	NSJ	SSJ	SCA	Cumulative adoption
$ 577.00	1,147				1,147
$ 579.00	2,095	3,379	3,512		10,134
$ 580.00	615				10,749
$ 585.00	3,750	3,322	14,063	8,138	40,023
Total acres adopted in each region	7,608	6,701	17,576	8,138	

Table 11: Regional entry price for canola (1.5 t/ac) and the number of acres adopted at each entry price.

Price of Canola ($/ton)	SAC	NSJ	SSJ	SCA	Cumulative adoption
$ 481.00	1,367				1,367
$ 482.00	1,817	1,525	1,619		6,329
$ 487.00	2,215	1,108	6,989	6,511	23,152
Total acres adopted in each region	5,399	2,633	8,608	6,511	

Table 12: Regional entry price for canola (1.75 t/ac) and the number of acres adopted at each entry price.

Price of Canola ($/ton)	SAC	NSJ	SSJ	SCA	Cumulative adoption
$ 412.00	928				928
$ 413.00	1,433	907	1,619		4,887
$ 418.00	4,038	4,000	6,989	6,511	26,425
Total acres adopted in each region	6,398	4,907	8,608	6,511	

Table 13: Regional entry price for canola (2 t/ac) and the number of acres adopted at each entry price.

Price of Canola ($/ton)	SAC	NSJ	SSJ	SCA	Cumulative adoption
$ 361.00	1,807				1,807
$ 362.00	3,353	3,997	1,619		10,776
$ 366.00	4,612	5,355	3,452	4,522	28,716
Total acres adopted in each region	6,398	4,907	8,608	6,511	

Crop adoption resulted in heterogeneous crop displacement effects by region, reflecting regional variation in cropping patterns.

Crop displacements vary across the regions as canola yield varies from 1.25-2 ton/acre, affecting the price needed to achieve the acres needed to produce 60 Mg of biodiesel/year within the state. Across all regions and canola yield, sudangrass, oat hay, and wheat are commonly among the five most affected crops across the regions; even though the magnitude of the displacement effects for each of these crops is different in each of the four regions. This highlights that biofuel feedstock crops compete first with low value forage crops, not those directly consumed as food. Figure 14 shows the acres of land displaced for the top five crops (by acreage) in each region when canola is adopted at the price where the total targeted acres for producing 60 Mg of biodiesel/year in the state is achieved (as shown in Table 9). Figure 14 shows the relationship between the price of canola and the aces of adoption across the four regions and the maps (Figure 15) show how the adoption of canola varies across clusters within each region as the yield of canola changed.

Figure 14: Top five crops displaced due to the adoption of canola.

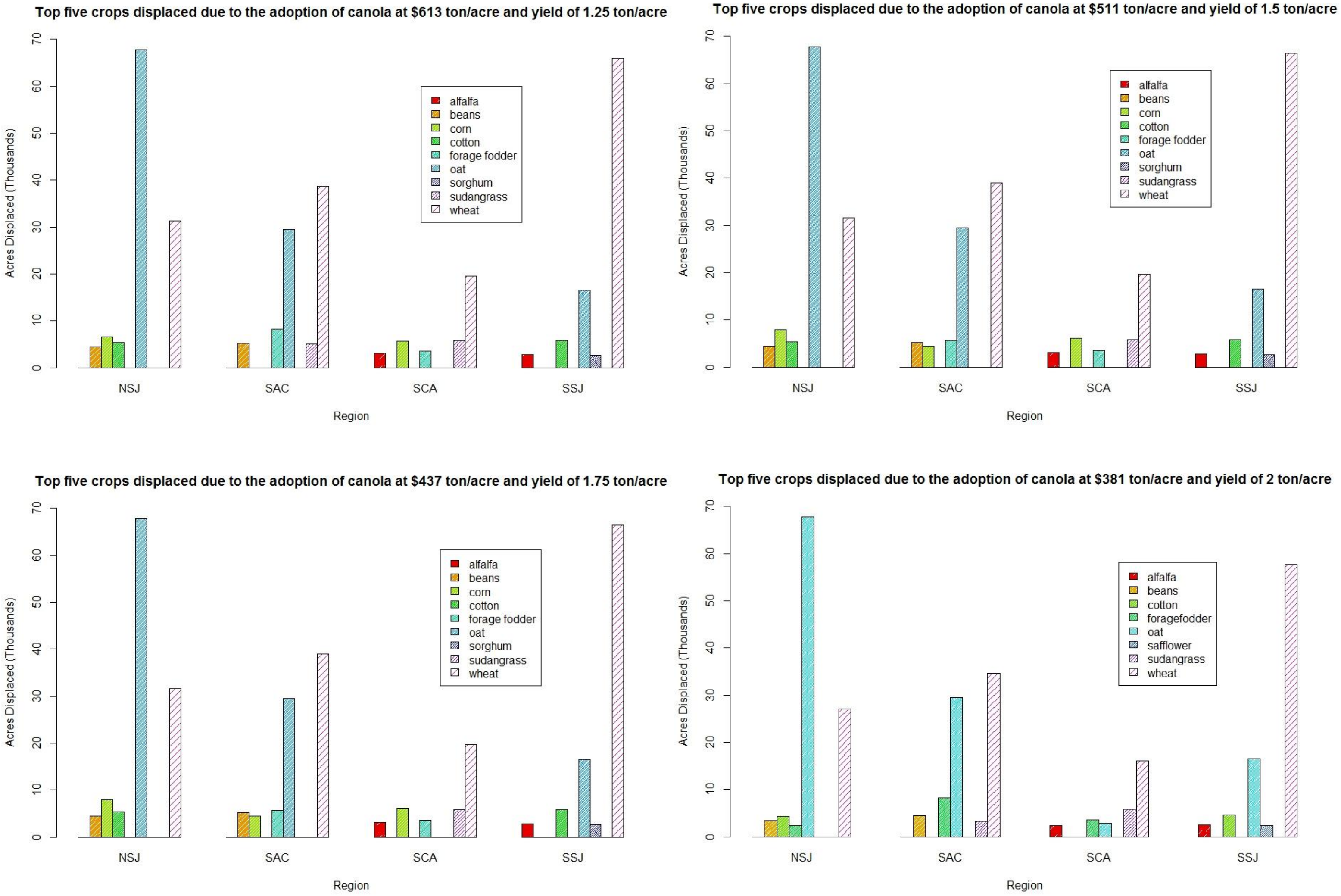
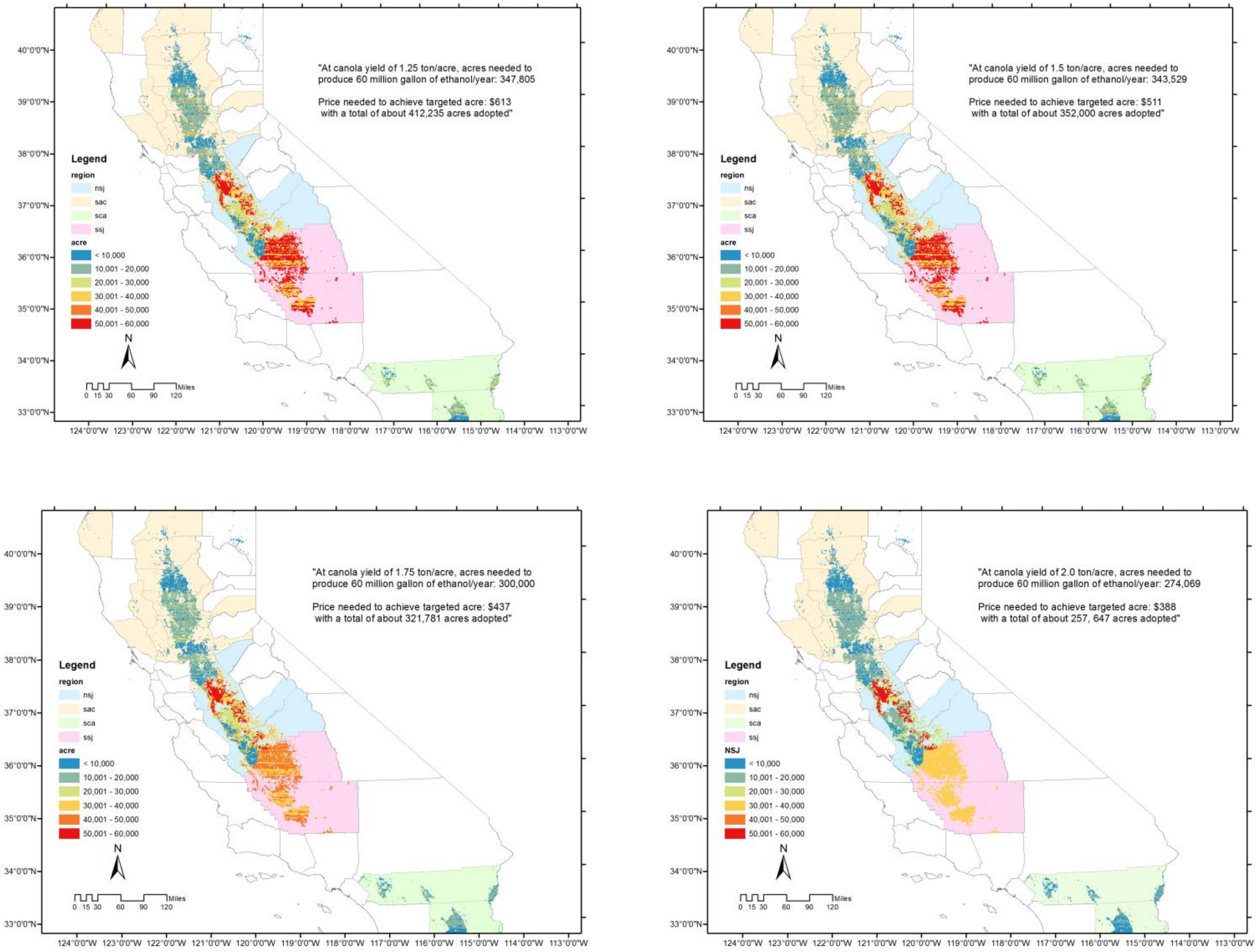


Figure 15: Acres of canola adopted at different yields.



"At canola yield of 1.25 ton/acre, acres needed to produce 60 million gallon of ethanol/year: 347,805

Price needed to achieve targeted acre: $613 with a total of about 412,235 acres adopted"

"At canola yield of 1.5 ton/acre, acres needed to produce 60 million gallon of ethanol/year: 343,529

Price needed to achieve targeted acre: $511 with a total of about 352,000 acres adopted"

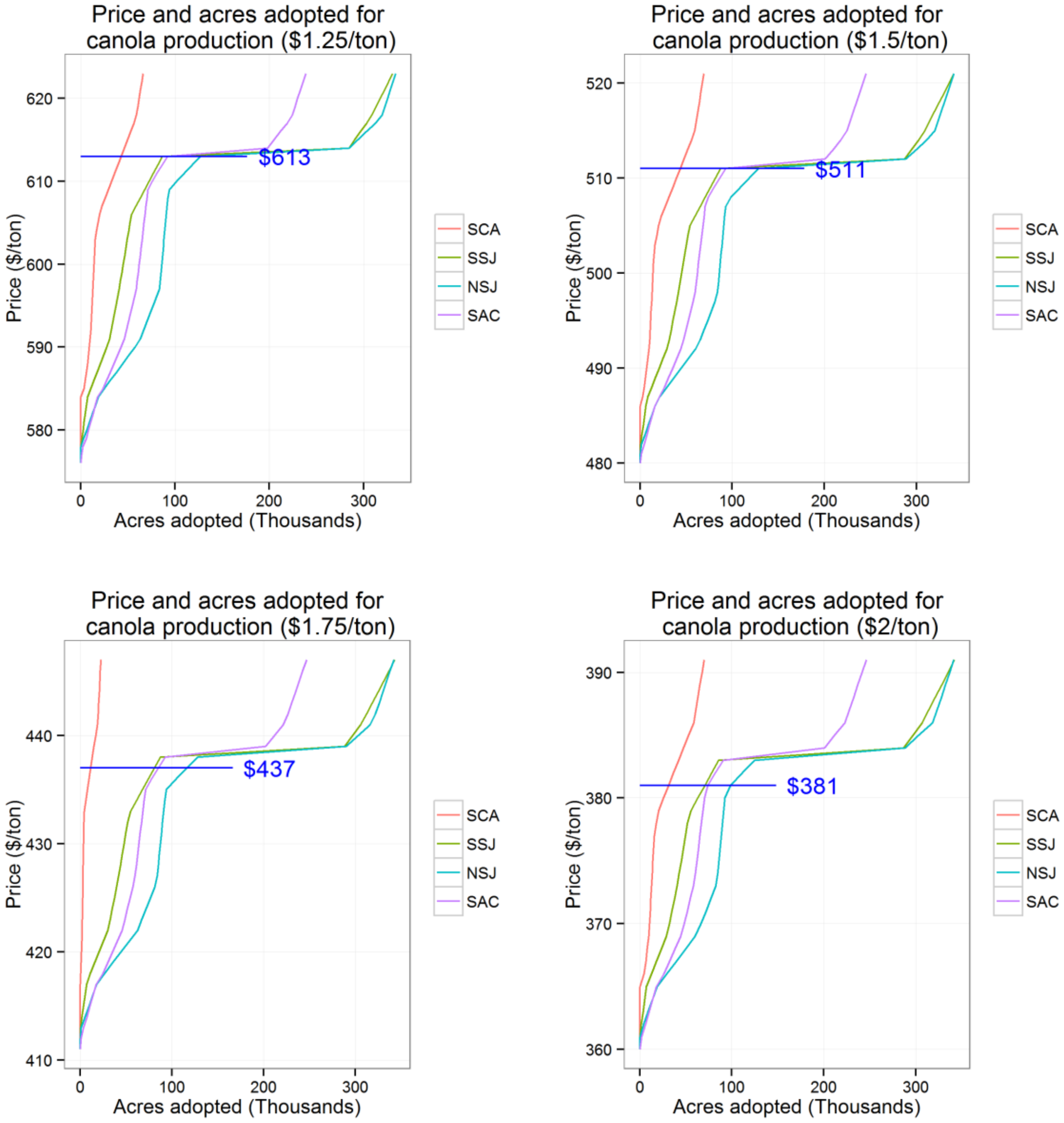
"At canola yield of 1.75 ton/acre, acres needed to produce 60 million gallon of ethanol/year: 300,000

Price needed to achieve targeted acre: $437 with a total of about 321,781 acres adopted"

"At canola yield of 2.0 ton/acre, acres needed to produce 60 million gallon of ethanol/year: 274,069

Price needed to achieve targeted acre: $388 with a total of about 257, 647 acres adopted"

Figure 16: Entry prices and adopted acres of canola.



Camelina

Camelina sativa is a winter annual oilseed crop similar to canola that may have utility in California cropping systems. Agronomic data from Kaffka et al. (2014) was used to analyze the adoption of Camelina in all five regions of the state. A similar planting and harvest date is assumed for all five regions (i.e. from November to May), which is one month to two months less inspiring than canola in practice. Higher prices were needed for Camelina crop adoption compared to canola due to both lower seed and oil percentage yields. Camelina uses less water and fertilizer N than canola as well. Yields were assumed (conservatively) to average 0.8 ton/ac of seed at 35% oil. Prices were increased iteratively by $1/ton until the price variable reached a maximum of $1,000/ton.

Using the BCAM simulation framework, the entry price range for each region, defined as the minimum price range in which the crop (in this case Camelina) begins to appear in the agricultural system in these five regions, was determined. Results are reported in Table 14. The SAC region has the greatest opportunity for Camelina adoption (i.e. 3,812 acres given a price range for Camelina of $796-$809/ton). On the other hand, the SSJ region appears to offer the least opportunity (i.e. about 1,000 acres given a price range of $801- $808/ton). These are very high prices and unlikely to be available to support Camelina adoption in commercial irrigated cropping systems. Entry prices for Camelina are much higher compared to canola despite their shorter growing season required. Both yields and the oil content of Camelina are lower as well, making it less likely to be an attractive feedstock to biodiesel producers, except during dry farming conditions, which are not adequately modeled here.

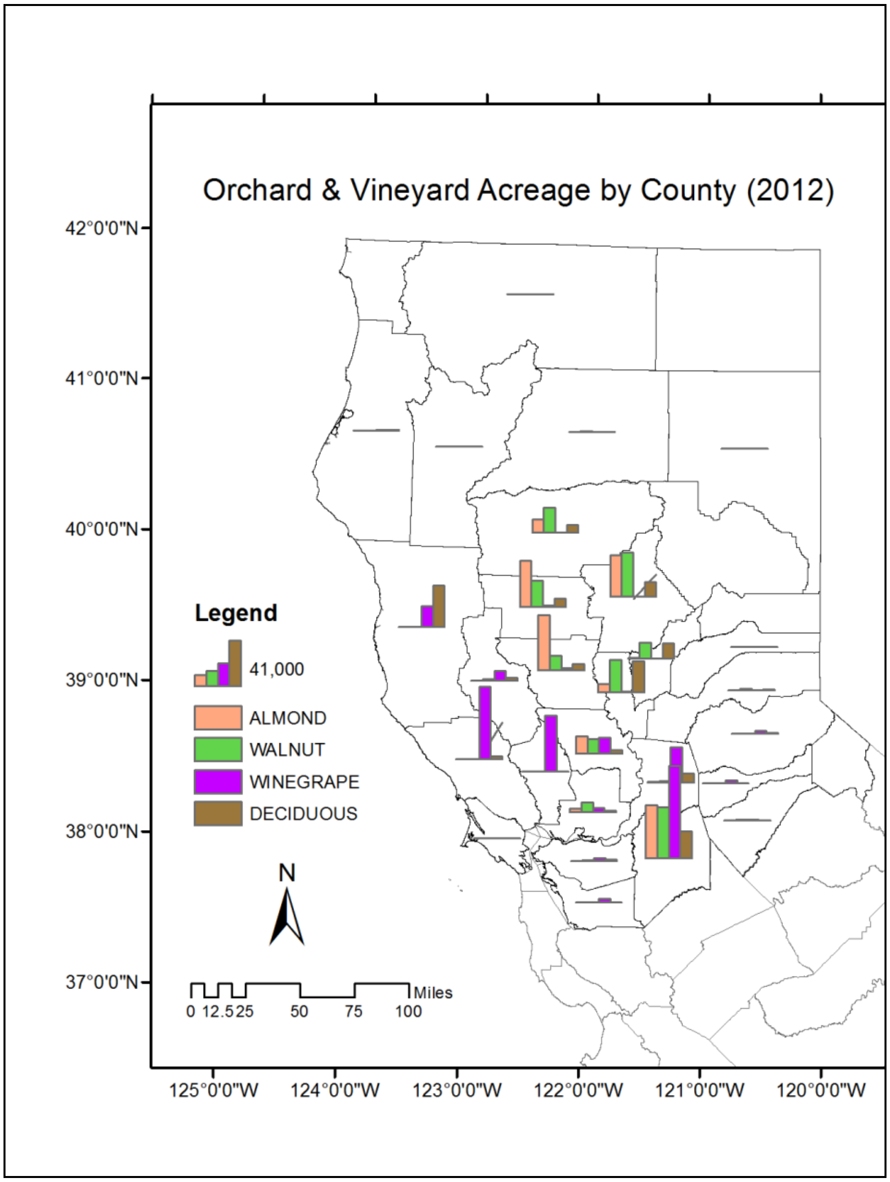
Table 14: Regional entry price for Camelina and the number of acres adopted at each entry price.

Price of Camelina ($/ton)	SAC	NSJ	SSJ	SCA	COA	Cumulative adoption
$ 795.00	5,533					5,533
$ 796.00	752					6,285
$ 801.00	1,537	2,019	326		387	10,555
$ 808.00	1,992	666	862	2,805		16,881
$ 809.00					230	17,111
Total acres adopted in each region	9,814	2,685	1,188	4,281	618	

Potential use for Camelina as a winter cover crop in orchards and vineyards

Camelina has lower seed yields and less oil in seeds than canola. Our analysis shows that Camelina production is uneconomical in most cropping regions due to these limitations. It may, however, have the potential as a cover crop in young orchards and in vineyards when planted between the rows in fall, and harvested in spring. By serving this purpose and also producing a bioenergy feedstock, a number of acres of land for oilseed production may become available. In this case, there would be no crop substitution effects. Research is currently underway evaluating this option. Figure 17 reports the number of acres of deciduous nut and fruit trees and vineyards in the northern part of the state. For the most part, average winter rainfall would be sufficient to support the production of a Camelina crop yielding 1600 lbs of seed per acre. Cover crops protect soils during winter from erosion, especially on slopping sites, and can add organic matter if incorporated. Weeds commonly grown during winter in any case and must be controlled. Deciduous nut and fruit trees are replaced as they age and become unproductive, and when replanted take several years to come into production. During that time (three to five years), some producers grow crops between the rows to generate income before the trees bare. This land provides a possibility for oilseed production. In vineyards, cover crops are sometimes grown, especially on slopping sites. Camelina matures in early May, and may not interfere with orchard or vineyard operations as much as a later maturing canola crop, so Camelina is presumed to be produced.

Figure 17: Deciduous fruit trees and vineyards in northern California counties with sufficient average winter rainfall for Camelina production (PUR data 2012).



If 25% of all vineyard producers and non-bearing acres are used for nut and tree fruit crops to produce Camelina as a cover crop, approximately 106K acres would be available per year in counties with average rainfall amounts sufficient for Camelina production. For vineyards, about 70% of the states vineyard acres are located in this region (plus Monterey and San Luis Obispo Counties where sufficient rainfall also occurs for the most part and where many vineyards are located on slopping sites). In vineyards, the use of every other row is assumed to allow winter access to vines, and half the surface area in orchards. These are all conservative assumptions. There could also be production in the San Joaquin Valley where rainfall is less if a small amount of water is available for winter application, but this prospect is not accounted here. Based on the amount of land estimated here, approximately 6.23 Mgge/y (Table 15) are potentially available from these land areas. If water were available in the San Joaquin Valley in amounts similar to the past, then a larger amount of feedstock could be produced.

In addition to the production of Camelina in orchards and vineyards, there may be ways in which crop production costs can be reduced. Production costs modeled here are conservative because they are similar to canola, but costs for Camelina might be reduced due to the use of reduced tillage systems, more conservative fertilizer and weed control practices, and improved yields. The potential for additional bidiesel production from waste resources like FOG may be limited (see *waste resources* below), so expansion of in-state biodiesel production may best be achieved with an increase in vegetable oils discussed here.

Table 15: Maximum cost of production per acre to break even.

	Yield (lb/ac)										
$/lb	**1200**	**1300**	**1400**	**1500**	**1600**	**1700**	**1800**	**1900**	**2000**	**2100**	**2200**
$ 0.10	$ 120.00	$ 130.00	$ 140.00	$ 150.00	$ 160.00	$ 170.00	$ 180.00	$ 190.00	$ 200.00	$ 210.00	$ 220.00
$ 0.20	$ 240.00	$ 260.00	$ 280.00	$ 300.00	$ 320.00	$ 340.00	$ 360.00	$ 380.00	$ 400.00	$ 420.00	$ 440.00
$ 0.30	$ 360.00	$ 390.00	$ 420.00	$ 450.00	$ 480.00	$ 510.00	$ 540.00	$ 570.00	$ 600.00	$ 630.00	$ 660.00
$ 0.40	$ 480.00	$ 520.00	$ 560.00	$ 600.00	$ 640.00	$ 680.00	$ 720.00	$ 760.00	$ 800.00	$ 840.00	$ 880.00
$ 0.50	$ 600.00	$ 650.00	$ 700.00	$ 750.00	$ 800.00	$ 850.00	$ 900.00	$ 950.00	$ 1,000.00	$ 1,050.00	$ 1,100.00
$ 0.60	$ 720.00	$ 780.00	$ 840.00	$ 900.00	$ 960.00	$ 1,020.00	$ 1,080.00	$ 1,200.00	$ 1,260.00	$ 1,260.00	$ 1,320.00

Energy (Sugar) Beets

Sugar beets were once grown throughout the state of California, from the Oregon border in Tulelake to near Mexico in the Imperial Valley. Over time, 11 sugar factories have operated in the state, but currently only one still does, in Brawley, Imperial Valley. Sugar beet yields there are the highest in the world (Panella et al., 2014). In 2014, two separate businesses (Mendota Advanced Beet Energy Cooperative and Thermal Energy Development Partnership, LP) are attempting to develop ethanol production based on beets as a feedstock. The Mendota Group is focused on beet production in both the NSJ and SSJ regions. The Tracey Group, however, is focused on the beet production in the NSJ and SAC regions.

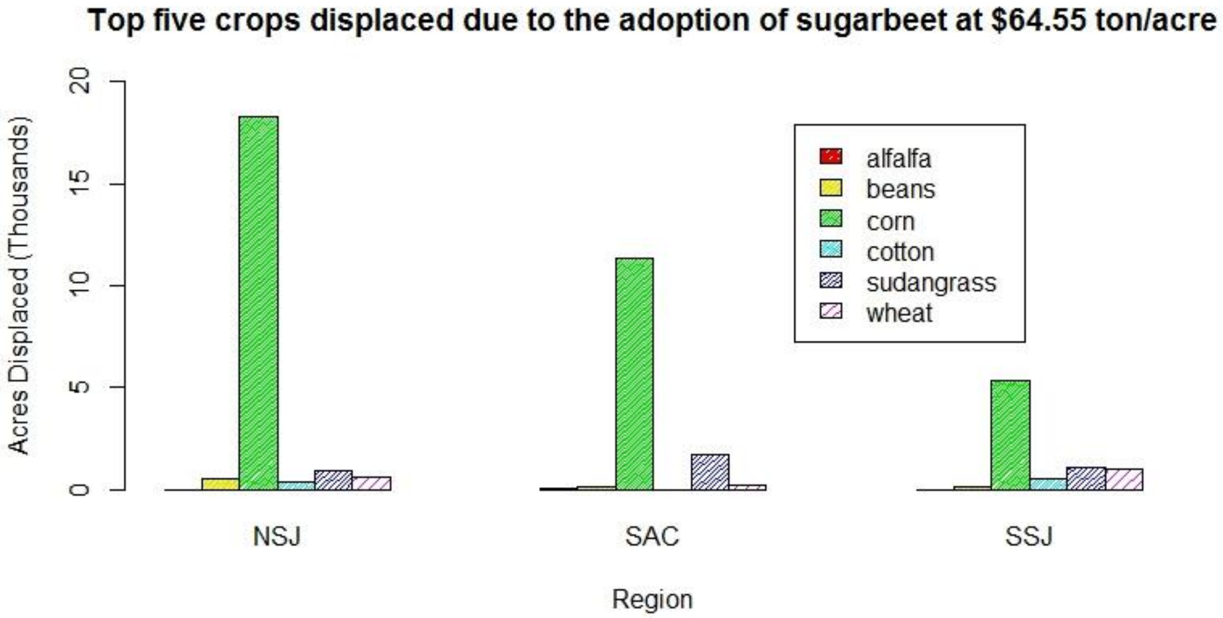
Based on discussions with both groups we assume that sugar beet is produced throughout the year (12 months). Beginning at $63.50/ton, sugar beet price was increased iteratively by $0.05/ton until $64.60/ton. The number of acres adopted for sugar beet in each region given different entry prices is shown in Table 16. The lowest prices at which sugar beet will be adopted are between $64.50 to $64.60/ton. Sugar beet has the greatest potential to be adopted in the SSJ region. The BCAM model shows that for a price range between $64.50 to $64.60/ton, a total of a little over 175,000 acres of land in the SSJ region will be adopted for sugar beet production.

The total acreage needed for sugar beet production to meet the demands of the two businesses is estimated to be approximately 60,000 acres based on company website and statements. At $64.55/ton a total of 39,497 acres is adopted. However, as the price of sugar beet increase to $64.60/ton, BCAM shows adoption to expand to unrealistic levels greater than 400,000, a larger amount of land than ever produced at peak land use for beets in the 1970's.[8] Figure 18 shows the acres of crops displaced due to the adoption of sugar beet in the SAC, NSJ, and SSJ region at $64.55/ton. Corn and sudangrass are consistently amongst the top two crops displaced across all three regions.

Table 16: Regional entry price for sugarbeets and the number of acres adopted at each entry price.

Price of Sugarbeet ($/ton)	SAC	NSJ	SSJ	Cumulative adoption
$ 64.50	5,370	7,846	3,011	16,227
$ 64.60	99,535	138,294	172,201	426,256
Total acres adopted in each region	104,905	146,140	175,212	

Figure 18: Top five crops displaced due to the adoption of sugarbeets.



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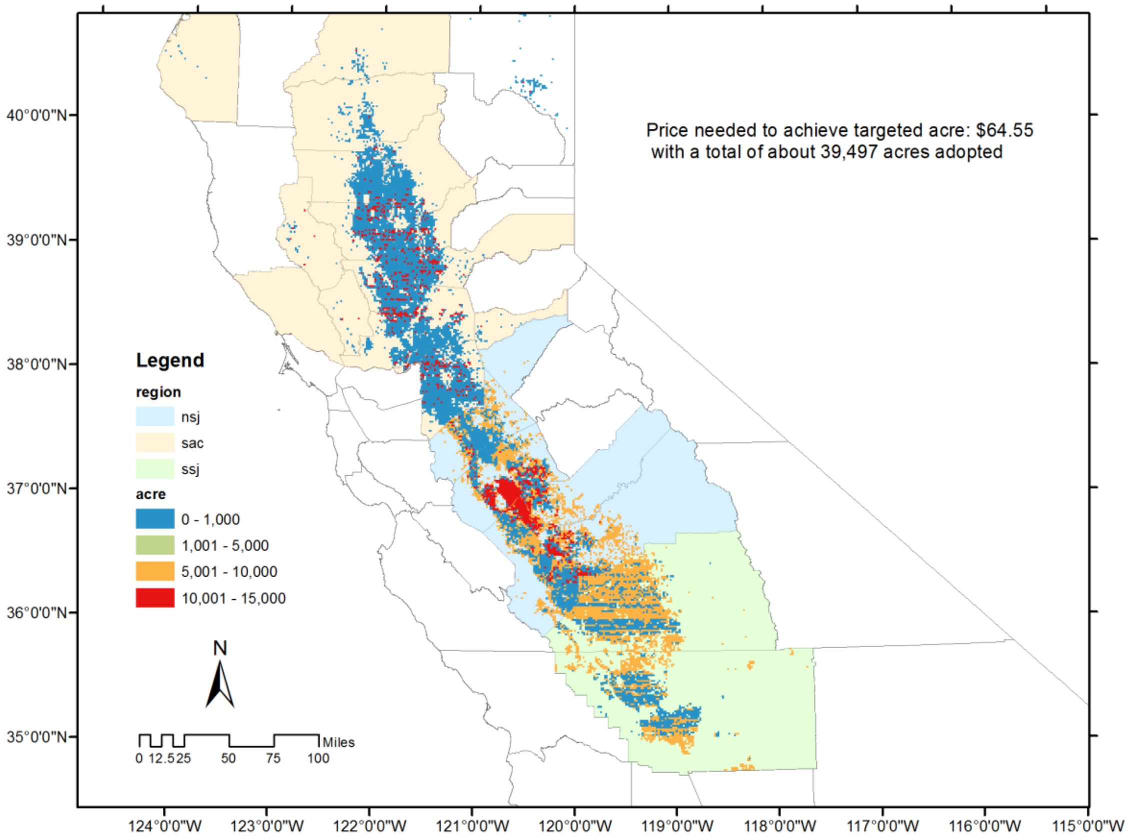
[8] BCAM does not incorporate agroecological limitations which affect crop expansion. For beets, aphid transmitted viruses and limits on rotation intervals= restrict acres. At small acreage such as that modeled here, there is no need to explicitly model agroecological limitations.

Figure 19: Map showing acres of sugarbeet adoption at $64.55 ($/t) in the NSJ, SSJ, and SAC regions.



Sugarbeet use as a biofuel feedstock in California is expected to include a novel practice of year-round harvest, from different subregions in each season of the year. Because California has a Mediterranean climate, such practices appear to be feasible. To more explicitly model year-round harvest, we conducted a detailed cluster analysis within the NSJ region with specific cropping and harvesting schedule as well as variation in irrigation requirements across all four seasons (i.e. fall, winter, spring, and summer). Each harvest region will require different planting and harvest dates, and affect cropping systems within the clusters in each region differently. Similarly, water use requirements will vary regionally for the same reason. The table below shows how the entry price of sugar beet production varies across seasons and clusters. For example, while cluster 4 is adopted at $64.50/ton in winter and summer, it is not adopted for sugar beet production until price is at least $64.60/ton in spring and $67.90 in the fall.

Table 17: Entry price ($/t) for sugarbeets in each cluster within the NSJ region and the number of acres adopted at each entry price.

Price of Sugarbeet ($/ton)	NSJ (Fall)	NSJ (Winter)	NSJ (Spring)	NSJ (Summer)
$ 63.50		53		
$ 64.45				156
$ 64.50		223	314	295
$ 64.60		2,498	319	1,295
$ 64.60		9,752	7,560	
$ 64.60			518	
$ 67.90	289			
$ 67.90	208			
$ 68.00	616			
$ 68.05	1,589			
Total acreage adopted	2,702	12,526	8,711	1,746
	Cluster 1	Cluster 2	Cluster 3	Cluster 4

In our analysis, we found that in order for there to be at least 4,000 acres of land adopted for sugarbeet production in each season within the NSJ region, the price of sugarbeet has to be at least $68.05/ton in the fall, $64.60/ton in winter and spring, and $64.75/ton in summer. Table 18 shows that sugar beet can be produced at the lowest price in the winter and the largest acreage is also adopted at the price of $64.60/ton. Figure 20 shows the top five crops displaced in each season at the prices shown in Table 18, i.e. at a price where there will be at least 4,000 acres adopted for sugarbeet production. While the types of crops displaced vary across region, most of the acres of crops displaced for these crops are relatively small (i.e. less than about 250 acres). Corn is consistently one of the top five crops displaced across all four seasons, the acres of land displaced for crop production varies across season (See Figure 20).

Table 18: Sugarbeet prices in each season for there to be at least 4,000 acres of land adopted for sugarbeet production in the NSJ region.

	Price ($/ton)	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Sum of acres in each season
NSJ (Fall)	$ 68.05	1,589	2,124	620	2,213	6,546
NSJ (Winter)	$ 64.60	150	2,498	9,752	863	13,263
NSJ (Spring)	$ 64.60	319	7,560	1,276	518	9,673
NSJ (Summer)	$ 64.75	1,457	628		1,953	4,037

Figure 20: Top five crops displaced due to the adoption of sugarbeets.

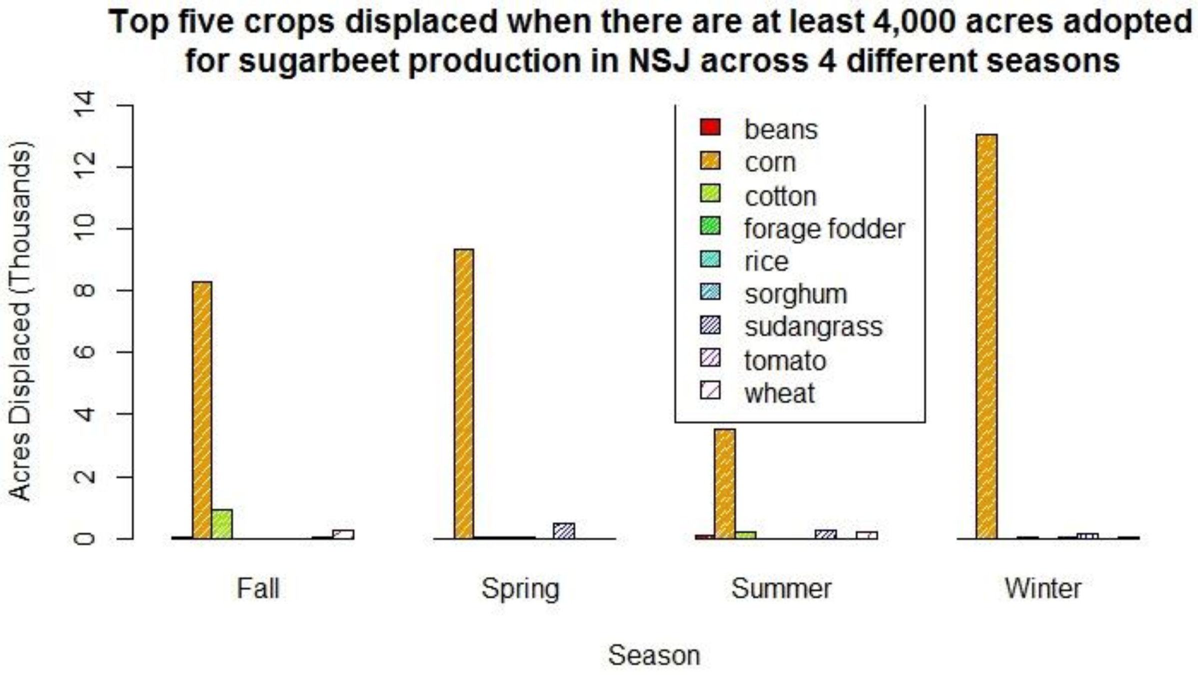


Figure 21: Year round harvest plan and regional harvest areas to support 12-month ethanol production from beets in the San Joaquin Valley.

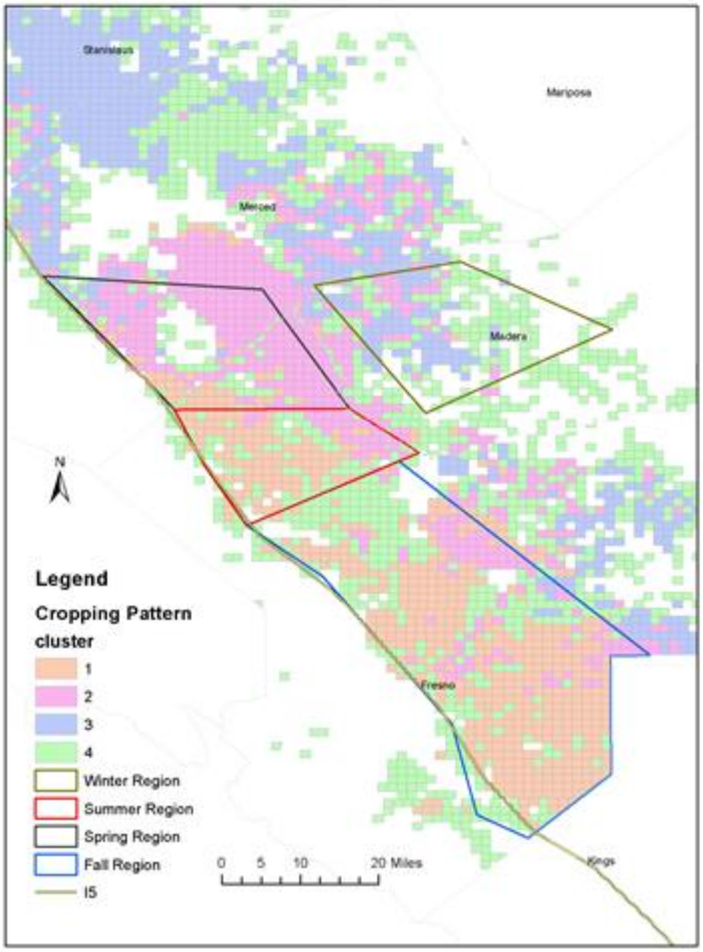


Table 19: Sugarbeet harvest schedule and regional source.

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
(2) SUMMER (Cantua Cr., Five Pts)	1	1	1	1	1	1	1	0	0	0	1	1
(3) FALL (Helm, San Joaquin)	0	0	1	1	1	1	1	1	1	1	1	0
(4) WINTER (Tracy, Patterson, Delhi, Atwater, Raisin City, Burrel, Utiva Ave)	1	1	1	0	1	1	1	1	1	1	1	1
(1) SPRING (Los Bano, Dos Palos)	1	1	1	1	1	1	1	1	1	1	1	1

Table 20: Estimated irrigation requirements for sugarbeet production in diverse harvest regions (ac-ft).

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
(2) SUMMER (Cantua Cr., Five Pts)	1.1	1.9	3.6	5.1	6.3	6.1	9.6	0	0	0	1	1.1	35.8
(3) FALL (Helm, San Joaquin)	0	0	1	2.5	3.3	8	9.6	8.3	6	3	2.5	0	44.2
(4) WINTER (Tracy, Patterson, Delhi, Atwater, Raisin City, Burrel, Utiva Ave)	2	2.5	3.6	0	1.1	3.5	8	9.6	6	3	2.5	2	43.8
(1) SPRING (Los Bano, Dos Palos)	2	2.5	3.6	1	3.3	8	9.6	8.3	6	3	2.5	2	51.8

Grain Sorghum

Based on Kaffka et al. (2013), we assume that grain sorghum is produced from May to November. Beginning at $156/ton, grain sorghum price was increased iteratively by $1/ton until at least 450,000 acres of land is adopted for grain sorghum production. The BCAM result shows that the entry price ($/ton) for grain sorghum is the same across all three regions (Table 21). At this price, the BCAM predicts that about 200,000 acres of land will be adopted for grain sorghum production across all three regions with the NSJ region supply the largest acreage of land (Table 21).

Table 21: Regional entry price ($/ton) for grain sorghum and the number of acres adopted in each region.

Price of Grain Sorghum ($/ton)	SAC	NSJ	SSJ	Cumulative adoption
$ 164.00	70,644	90,850	38,972	200,467

Figure 22 shows the types of crops displaced due to the adoption of grain sorghum in the SAC, NSJ, and SSJ region. Oat and corn are the two crops that are displaced by crop adoption across all three regions.

Figure 22: Top five crops displaced due to the adoption of grain sorghum.

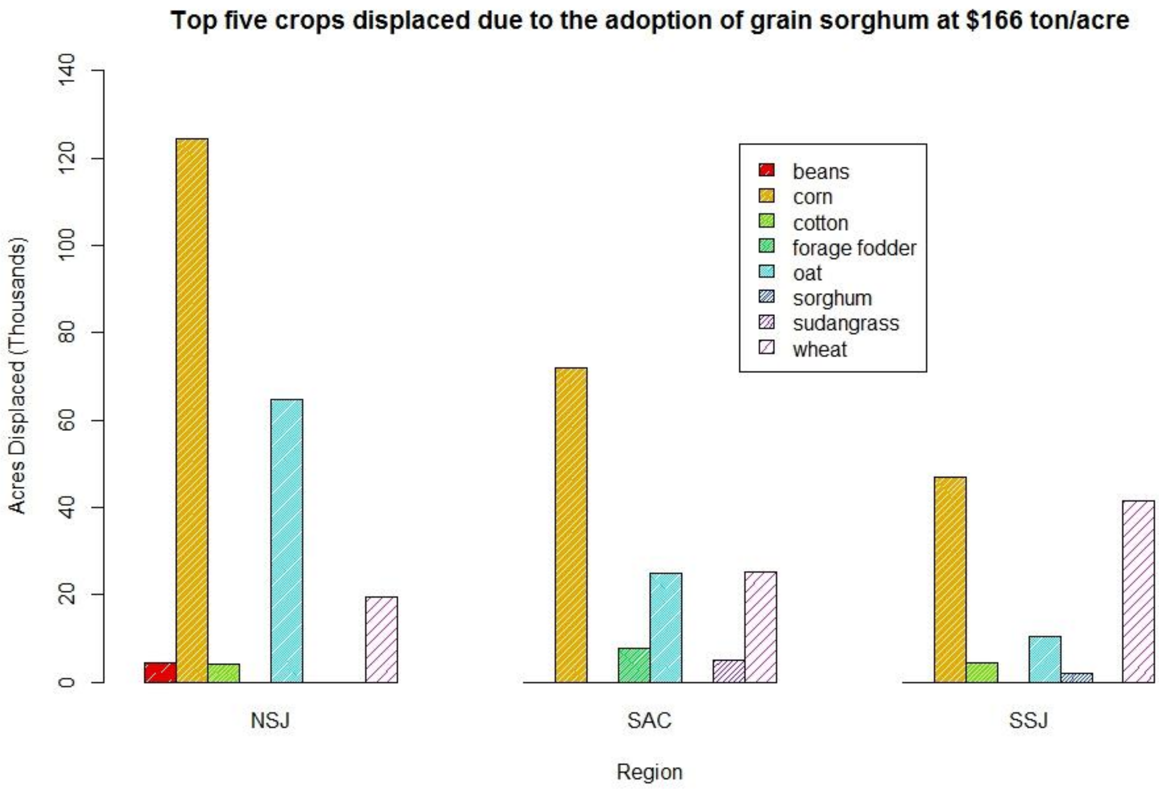
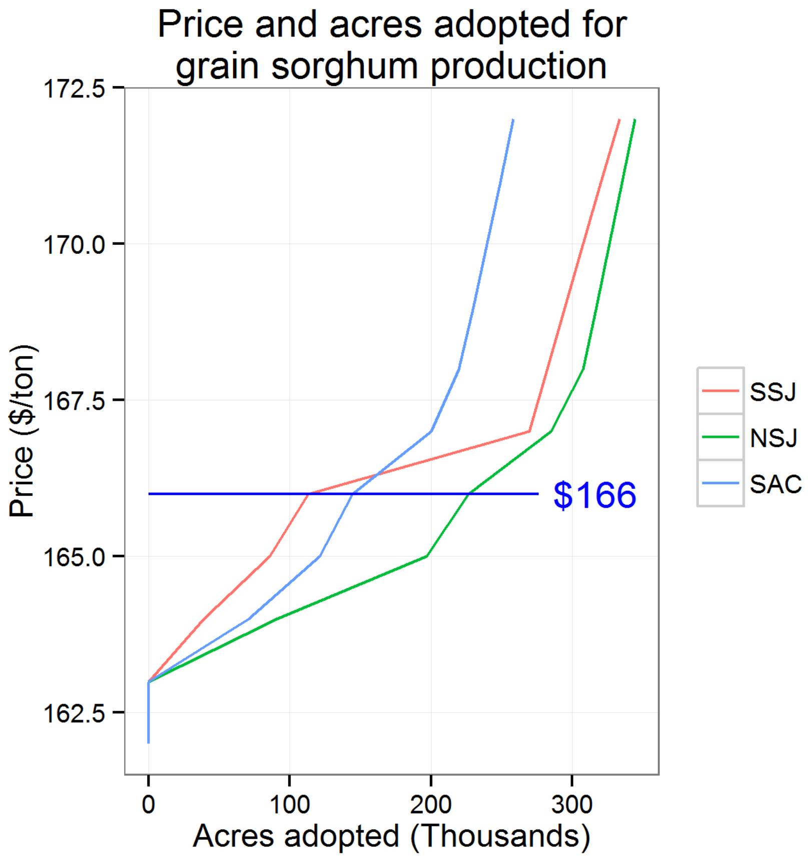


Figure 23: Entry prices and adopted acres of grain sorghum.



Sugarcane and Energy Cane

Analysis of sugarcane was restricted to Imperial Valley. Here, sugarcane and energy cane (a related species) are considered identical in terms of costs and yields. Sugarcane is a short-lived perennial likely to be grown for 5 years in California desert farming regions, the first year for establishment and five years for production (Kaffka et al., 2014). Beginning at $47.55/ton, the price of sugarcane was increased iteratively by $0.1/ton until at least 110,000 acres of land is adopted for sugarcane production in the Imperial Valley, which is the acreage target as reported in the California Ethanol and Power. For sugarcane to be adopted in the Imperial Valley; the price has to reach a minimum of $47.10/ton and at this price about 5,000 acres of land will be adopted (Table 22). For at least 110,000 acres of land to be adopted, the price of sugarcane has to reach at least $48.90/ton and at this price wheat is displaced by the greatest acreage (see Figure 24). Based on the prices used here, wheat is a relatively low valued crop. If the market price of wheat were to rise relative to sugarcane or energy cane, then additional displacement of forage crop acres (Sudan grass hay, Bermuda grass hay, and alfalfa) would be likely.

Table 22: Regional entry price for sugarcane and the number of acres adopted in each cluster within the Imperial Valley.

Price of Sugarcane	Cluster 1	Cluster 2	Cluster 3	Cumulative adoption
$ 47.10		908	4,026	4,933
$ 47.30	1,151			6,085

Figure 24: Crops displaced due to the adoption of sugarcane.

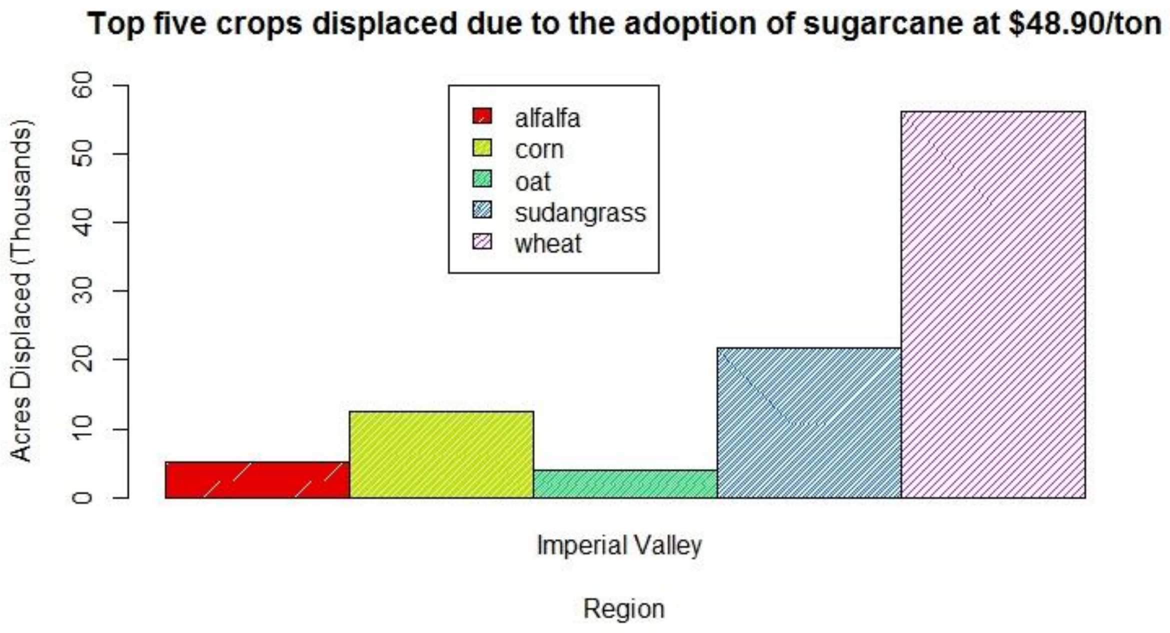


Figure 25: Entry prices and adopted acres of sugarcane.

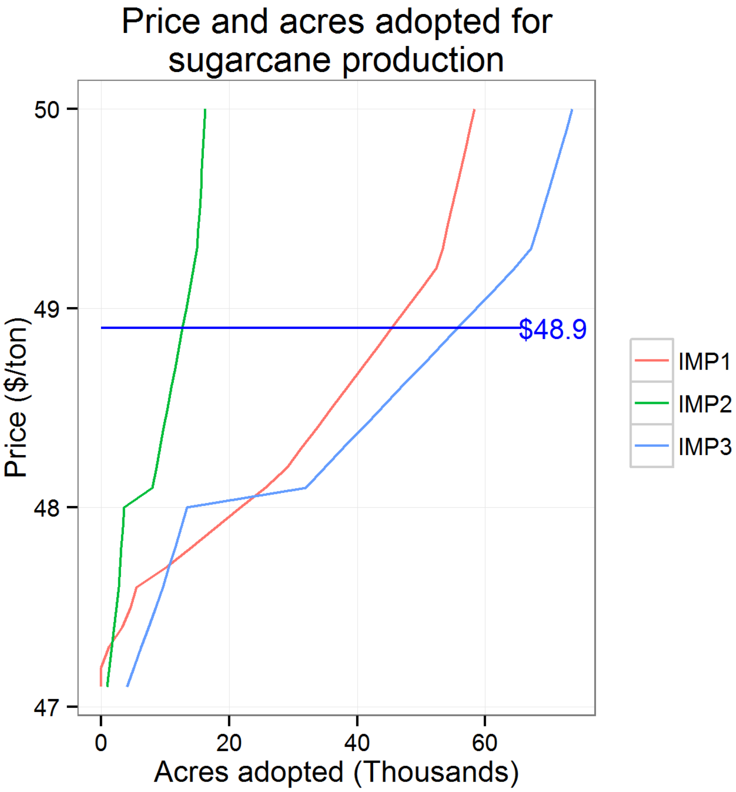


Table 23: Number of acres adopted for sugarcane production at different price levels

Price of Sugarcane ($/t)	Acreage adopted for sugarcane in the Imperial Valley
$ 47.55	
$ 47.65	3,039
$ 48.65	39,058
$ 49.65	61,630
$ 50.65	67,551
$ 51.65	73,324
$ 52.65	79,006
$ 53.65	84,641
$ 54.65	90,244
$ 55.65	95,776
$ 56.45	100,200

4. New employment opportunities and secondary and tertiary effects associated with bioenergy crop based biorefineries in California (IMPLAN).

Agricultural feedstock based businesses employ a large number of people in feedstock production, assembly and transport, and result in manufacturing jobs, often in rural areas with underserved populations. Estimates of jobs associated with the construction and operation of a biorefinery plant are provided here. Input-output analyses are reported for a sugar beet, biodiesel, and sugarcane businesses. Using irrigation water for feedstock production, the production of biofuels or biopower can spur local economic growth and development and lead to the creation of high-quality job opportunities.

Jobs from potential California biorefineries based on agricultural feedstocks

David Roland-Holst and colleagues (2009) has studied the effects of adopting energy efficiency and GHG reduction policies on job generation in California. The oil and gas industry does not generate many jobs per unit of economic activity based on this analysis, especially compared to new energy efficiency and manufacturing jobs in the state. They suggest that a dollar saved on traditional energy is a dollar earned by 10-100 times as many new workers (Roland Holst et al. 2009). They foresee that the growth of an in-state biofuels sector and plug-in hybrid and other alternative vehicle technologies will result in significantly greater employment opportunities. Similarly, analyses by the US Department of Commerce (2006) emphasized impressive rural employment and welfare gains associated with the expansion of the grain-based ethanol industries, mostly in the Midwest.

Job and economic activity projections from one energy beet biorefinery, a sugarcane ethanol system in the Imperial Valley, and expanded biodiesel production in central California are evaluated based on IMPLAN analysis and assumptions about the productivity of these facilities derived from self-reported descriptions or conversations with the companies themselves.

Biofuel companies commonly report jobs associated with their biorefineries and jobs created in the construction of the facilities. Some also report jobs correlated with feedstock production, harvesting and assembly. Selected estimates are provided in Table 24.

Table 24: Biorefineries and associated permanent and temporary jobs.

Company	Location	RFS	Feedstock	Capacity	Jobs announced	
	City, State			(Million gallons per year)	Biorefinery	Total potential
Pacific Ethanol, Inc	Sacramento, CA	ethanol	sorghum	200	222	372
Mendota Bioenergy	Mendota, CA	ethanol	sugar beet	1	50	350
California Ethanol and Power Project	Imperial Valley, CA	ethanol	sugarcane	66	240	1200
Canergy	Imperial Valley, CA	ethanol	energy cane	25	100	
Community fuels	Encinitas, CA	biodiesel	canola oil	21.8	34	
Bently Biofuels|Got Grease?	San Francisco, CA	biodiesel	used cooking oil		12	
Springboard Biodiesel LLC	Chico, CA	biodiesel	any vegetable or animal oil, including used cooking oil	0.35	12	
North Star Biofuels	Watsonville, CA	biodiesel	animal fat	22.75	14	
Poet-DSM Advanced Biofuels	Emmetsburg, IA	ethanol	cellulosic and organic (corn cobs)	20		240
INEOS Bio	Vero Beach, FL	ethanol	cellulosic	8*		400
USDA & Chemtex	Sampson County, NC	ethanol	energy grasses and agricultural waste	20	65	
Dubay-Biofuels	Greenwood, WI	ethanol	waste product from cheese production	5	150	
Beta Renewables[1]	Crescentino, Italy	ethanol	cellulosic	19.8	100	300
FL Biofuels LLC	Lee County, FL	biodiesel	waste vegetable oil	2.1	14	
Green Energy Partners	Maribel, WI	biogas	food waste	N/A	20	

Notes: # including construction, cultivation, harvesting, etc.; *plus 6MW power per year. Boundaries of these diverse systems are defined differently by each company. Biorefinery positions could include the feedstock cultivation, transport, and biorefinery operation, etc. Temporary positions include construction, engineering and design, and others (included in total). Permanent jobs to operate the biorefinery facility are listed in that column. Plant locations may not reflect the exact location of the installation, but rather the closest city or county. Biodiesel: **Source:** Data from the Alternative Fuels and Advanced Vehicles Data Center (AFDC) station locator. Ethanol **Source:** NREL, Renewable Fuels Association (RFA). Data is updated every two months. See also: Renewable Fuels Association (RFA), Ethanol Producer.

IMPLAN Based Estimates: Background

There are three established, traditional input-output economic impact models in use in the United States. They are RIMS, developed and operated by the US Department of Commerce, Bureau of Economic Affairs (BEA); the private Regional Economic Models, Inc., (REMI); and the private, IMPLAN (IMpact analysis for PLANning) system by IMPLAN Group, LLC. A broad comparison on multipliers and factors between the three models was conducted by Rickman and Schwer (1995). They asserted that IMPLAN would provide the greatest flexibility and efficiency in allocation of time. IMPLAN is a private, economic data and software provider that compiles US economic data on state and county levels by year, and sells the data to independent users. The structure and set up of economic impact analyses has great flexibility, but the data, settings, and filters selected, affect model predictions. IMPLAN analysis relies on existing technologies and economic data for its predictions. New biorefineries must be modeled by analogy with existing ones, so results are only estimates based on analogy.

IMPLAN software is commonly used to estimate detailed local and regional effects from the establishment of new businesses[9]. IMPLAN is used in numerous studies to assess the economic impact of a new economic activity. For example, Bergstom et al. (1990) have used IMPLAN to study the economic impacts of recreational spending on rural areas and Lazarus and Tiffany (2009) also used IMPLAN to look at the economic impact of using short rotation woody biomass to support energy production in Minnesota. It is used here to estimate the economic effects of three model potential biofuel feedstock-biorefinery businesses that have reasonable chances of being developed in California. These are an expanded biodiesel manufacturing operation using vegetables oils produced in-state located near the Delta region, an ethanol biorefinery using energy beets in the San Joaquin Valley, and a sugarcane refinery in the Imperial Valley[10].

Inputs for the Model in IMPLAN

Details for the IMPLAN economic impact analysis are derived from information about three companies attempting to create biorefineries in the state or expand current operations based on public documents and information from the companies themselves[11]. The results reported here are model estimates and may differ from the actual scale, design and location of any business

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[9] "IMPLAN software consists of (1) an input-output data base; (2) several program modules for constructing inter-industry models for the user designated impact region; and (3) a model that calculates the direct, indirect, and induced effects of changes in final demand. The IMPLAN input-output data is composed of a national-level technology matrix and county-level estimates of final demand, final payments, gross output, and employment for economic sectors" Bergstrom et al. (1990).

[10] Model construction is discussed in APPENDIX xxx

[11] These are the Mendota Advanced Beet Energy Coop LLC, California Ethanol and Power, and Community Fuels.

that is established. The prices used to calculate the value of the feedstock, value of the fuel, and value of the co-products are based on recent market prices.[12]

A biodiesel plant using canola oil is based on an estimated crop yield of 1.25 tons per acre with 42-44% oil when crushed (Kaffka et al., 2014). Canola oil has low saturated fatty acids, which results in FAME biodiesel with a lower cloud point and other favorable characteristics. We assumed that 100,000 acres of canola were adopted statewide and the seed supply needed to support an expanded biodiesel plant. We further assume that the biodiesel plant achieves the conversion ratio 1:1 of biodiesel to oil and 10-20% glycerin.[13] The construction cost was based on estimates for other canola biodiesel plants (van Gerpen, 2008). The operational cost of the biodiesel plant was based on the process reported by Community Fuels[14].

The sugar beet ethanol plant was based on the final project report by Mendota Bioenergy Fuel in 2012 to the state's ARFVTP, including the construction and operation cost for the sugar beet ethanol unit. Although sugarcane ethanol plants play a very important role for fuel and energy in Brazil, the constraint for feedstock cultivation limits the expansion of this conversion technology to the Imperial Valley. California is one of the few states which could produce new sugarcane supplies and thus adopt the technology used for Brazilian sugarcane ethanol plants. For the purposes of estimating its economic impact analysis, the sugarcane ethanol plant was simulated based on a typical Brazilian sugarcane plant (Somerville et al., 2010; Chum et al. 2014). The IMPLAN input data used to estimate the economic impact of each activity is presented in Table 25.

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[12] Biogas price calculation is based on the natural gas price and the energy (biogas: 600 BTU per cubic foot versus natural gas 1000 Btu per cubic foot). Natural gas: $7.71/MMBtu for industrial, pipeline CH4 in California, monthly, Feb-14 (Source: http://www.eia.gov/dnav/ng/ng_pri_sum_dcu_nus_a.htm). Based on this information, a biogas price of $4.63 per thousand cubic feet biogas is used, since biogas density is 1.15 kg/cubic meter, it is equivalent to $142 per tons of biogas. Glycerin price calculation is based on crude glycerin (80%) FOB Midwest price of $0.1200/lb. Hence, $0.12 per lb *10.523 lbs per gallon=$1.26 per gallon (Source: www.opisnet.com/images/productsamples/EBISnewsletter-sample.pdf)

[13] http://www.energyfuturecoalition.org/biofuels/fact_biodiesel.htm
http://www.biodiesel.org/what-is-biodiesel/biodiesel-fact-sheets

[14] Available at: http://www.communityfuels.com/wp/wp-content/uploads/2014/01/CVBJ-4-2012.pdf

Table 25: Input data for the three biorefinery plants in California.

Type of biorefinery facility	Location	Feedstock	Level of feedstock (tons)	Value of Feedstock	Level of biofuel produced	Value of fuel	Co-product	Yield	Value of co-product	Construction cost (CAPEX)	Operation cost (OPEX)
Ethanol plant	Fresno, CA	Sugar beet	1,140,000	$48,279,000	30,000,000	$81,000,000	biogas	48,000 ton	$6,816,000	$38,000,000	$20,121,000
Biodiesel plant	San Joaquin, CA	Canola seed	125,000	$59,375,000	16,143,750	$65,382,188	glycerin	3,549,688 gal	$4,472,607.00	$28,628,882	$3,228,750
Ethanol plant	Imperial, CA	Sugarcane	2,700,000	$121,500,000	71,300,000	$192,510,000				$86,706,741	$1,322,508

Table 26: The components of production costs of three biofuels.

Crop	Fuel type	Yield (as harvested)		Total CAPEX	CAPEX	CAPEX	Total OPEX	OPEX	OPEX	Total	Total	Feedstock of total
		gal/t	gge/ton	$	$/gal	$/gge	$	$/gal	$/gge	$/gal	$/gge	%
Canola	biodiesel	129.15	135.22	1791631	3.41	3.26	105000	0.2	0.19	3.61	3.45	82.5
Beets	ethanol	25.2	16.8	38000000	1.27	1.9	34440000	1.15	1.72	2.41	3.62	65.8
Sugarcane	ethanol	21.54	14.36	86706741	1.22	1.82	1322508	2.09*	3.13*	*3.30	*4.95	63.2*

*The energy beet biorefinery model includes three complex technologies (gasification of woody biomass residues), ethanol fermentation and distillation, and anaerobic fermentation. The OPEX costs include all three technologies and overestimate the cost of ethanol production alone.

Table 26 summarizes the results for the different components of production costs modeled by IMPLAN. Canola oil for biodiesel production has the highest feedstock share of total production cost. However, beet ethanol resulted in comparable total costs per gge to biodiesel. Sugarcane input data was based on typical Brazilian ethanol plants. However, the feedstock cost was up to $3.13 per gge with a BCAM entry price of $45 per ton as harvested in California compared with an estimate of $1.48 per gallon (equal to $2.22 per gge based on an earlier estimate for sugarcane of $28.9 per ton (Shapouri, 2006). Feedstock cost as modified is ~63.2% of total cost. Energy from electricity or biogas production or by product sales converted to an energy equivalent is not provided.

Results

Overview of the economies in the San Joaquin, Fresno, and Imperial Counties

In 2010, the Gross Regional Product (GRP) in Fresno was about 6 times larger than the GRP in Imperial County. IMPLAN produces this data in economy-wide values with the exception of the average household income (total personal income/total households). The average household income is about the same in San Joaquin and Fresno county and slightly higher in Imperial County. Since this economic impact is tied to a land-based industry, a section (presented in italics) was added with selected characteristics in terms of the land area (square miles). Here the wealth per land area unit (GRP/square mile) in San Joaquin County is about 12 times greater than the Imperial County. The number of households,as well as population per square mile, are also higher in San Joaquin County than in Fresno and Imperial County.

Table 27: Summary of economies in San Joaquin, Fresno, and Imperial Counties from IMPLAN.

County	**San Joaquin**	**Fresno**	**Imperial**
Model Year	**2010**	**2010**	**2010**
GRP	$21,965,310,701	$33,014,011,739	$5,320,928,974
Total Personal Income	$20,823,880,000	$28,138,740,000	$4,874,060,000
Total Employment	266,208	421,173	71,794
Number of Industries	290	296	183
Land Area (Sq. Miles)	1,399	5,963	4,175
Population	683,494	924,691	169,354
Total Households	219,157	291,553	46,678
Average Household Income	$95,018	$96,513	$104,419
Population per Square Mile	489	155	41
GRP per Square Mile	$15,700,722.45	$5,536,476.90	$1,274,474.01
Personal Income per Square Mile	$14,884,832.02	$4,718,889.82	$1,167,439.52
Households per Square Mile	157	49	11
Value Added			
Employee Compensation	$10,939,091,842	$16,480,820,749	$2,816,405,239
Proprietor Income	$2,111,388,341	$3,751,052,480	$547,103,748
Other Property Type Income	$7,230,323,165	$10,345,651,002	$1,557,092,029
Tax on Production and Import	$1,684,507,354	$2,436,487,508	$400,327,959
Total Value Added	$21,965,310,701	$33,014,011,739	$5,320,928,974
Final Demand			
Households	18,148,120,306	24,910,486,261	4,107,941,436
State/Local Government	$2,854,922,129	$4,584,847,607	$1,733,218,877
Federal Government	$1,084,032,055	$2,567,643,343	$1,016,424,422
Capital	$1,949,183,368	$4,121,478,294	$313,673,963
Exports	$14,922,949,732	$22,528,607,406	$4,062,878,606
Imports	($16,103,609,193)	($24,431,058,153)	($5,624,916,853)
Institutional Sales	($890,287,721)	($1,267,993,069)	($288,291,428)
Total Final Demand	$21,965,310,675	$33,014,011,690	$5,320,929,022

Scenario Analysis

Table 27 summarizes the economic impact of the construction of the biorefinery alone in 2014 Table 28 summarizes the economic impact of all of the above activities, which includes the construction of the biorefinery; the operation of the biorefinery; the production of the respective feedstock, i.e. canola seed, sugar beet, or sugarcane; the production of fuel; and co-products for each biofuel plant in each county. Table 30 through Table 32 summarizes the top ten industries by employment affected by all of the above mentioned economic activities in each county.

Direct Effect *= values known to be associated with the specific activity*

Indirect Effect *= values from support industries (derived from historical data in the model)*

Induced Effect *= values from additional spending and consumption from additional economic activity*

The IMPLAN software is set up for an expected, known economic direct effect to be entered for a specific event within each activity. Then the software relies on historical economic relationships between subsectors to calculate the indirect and direct effects. There are different influences regionally and between activities in the relationships between direct, indirect, and induced effects.

The preliminary results predict that biorefinery construction alone can result in the creation of 9, 210, and 505 jobs in San Joaquin, Fresno, and Imperial County, respectively (see Table 28). In our preliminary analysis, the value of biorefinery construction alone makes up a large proportion of the overall economic impact based on employment numbers. The construction and operation of a biorefinery will not only have an economic impact on the bioenergy industry alone but will also have an impact on other non-related industries such as offices of physicians, dentists, and other health practitioners, food services and drinking places, as well as retail stores (see Table 30 through Table 32).

Table 28: Summary of the economic impact of the construction of each biorefinery.

Impact Type	Employment	Labor Income	Value Added	Output
San Joaquin County-Canola Seed Biodiesel Plant				
Direct Effect	150.2	$11,045,783	$13,748,596	$28,682,882
Indirect Effect	45.5	$2,449,180	$3,775,216	$6,711,722
Induced Effect	78.8	$3,273,279	$6,471,288	$10,218,244
Total Effect	274.5	$16,768,243	$23,995,100	$45,612,848
Fresno County--Sugarbeet Ethanol Plant				
Direct Effect	210	$13,434,802	$17,228,386	$38,000,000
Indirect Effect	69	$3,623,056	$5,438,330	$9,303,782
Induced Effect	107	$4,478,436	$8,695,275	$13,808,331
Total Effect	388	$21,536,294	$31,361,991	$61,112,113
Imperial County-Sugarcane Ethanol Plant				
Direct Effect	505	$28,220,833	$37,308,853	$86,706,471
Indirect Effect	114	$5,178,721	$8,013,771	$14,203,807
Induced Effect	124	$3,891,602	$8,843,710	$13,779,150
Total Effect	743	$37,291,155	$54,166,333	$114,689,428

Table 29: Summary of the economic impact of all the activities involved for constructing and operating a biorefinery.

Impact Type	Employment	Labor Income	Value Added	Output
San Joaquin County-Canola Seed Biodiesel Plant				
Direct Effect	645.7	$19,980,262	$43,687,243	$89,466,246
Indirect Effect	258.6	$10,650,933	$22,092,833	$35,662,847
Induced Effect	179.8	$7,458,888	$14,751,822	$23,278,083
Total Effect	1084.1	$38,090,083	$80,531,898	$148,387,176
Fresno County--Sugarbeet Ethanol Plant				
Direct Effect	1,557.7	$36,759,029	$61,251,617	$188,423,348
Indirect Effect	1,088.8	$25,140,452	$52,390,525	$91,291,439
Induced Effect	391.1	$16,238,401	$31,535,316	$50,065,033
Total Effect	3,037.50	$78,137,882	$145,177,458	$329,779,819
Imperial County-Sugarcane Ethanol Plant				
Direct Effect	2,530	$73,943,203	$129,867,621	$404,664,654
Indirect Effect	1,140	$34,477,301	$68,160,231	$119,050,938
Induced Effect	403	$12,663,388	$28,789,916	$44,838,729
Total Effect	4,074	$121,083,892	$226,817,769	$568,554,321

**Proxy for sugarcane used in IMPLAN.*

Table 30: Top ten industries by employment affected by the construction and operation of a biodiesel plant in San Joaquin County, California.

Sector	Description	Employment	Labor Income	Value Added	Total Output
1	Oilseed farming	495.9	$ 8,943,622	$ 29,969,283	$ 60,825,543
36	Construction of other new nonresidential structures	150.2	$ 11,045,783	$ 13,748,596	$ 28,682,882
19	Support activities for agriculture and forestry	91.0	$ 3,180,992	$ 3,118,312	$ 3,698,040
360	Real estate establishments	57.0	$ 1,065,065	$ 9,839,603	$ 11,667,146
413	Food services and drinking places	25.2	$ 510,416	$ 841,172	$ 1,574,430
319	Wholesale trade businesses	10.7	$ 692,926	$ 1,383,355	$ 1,587,934
354	Monetary authorities and depository credit intermediation activities	10.5	$ 563,531	$ 2,219,033	$ 4,688,559
369	Architectural, engineering, and related services	9.8	$ 600,725	$ 615,052	$ 1,159,521
355	Nondepository credit intermediation and related activities	9.6	$ 551,331	$ 651,833	$ 1,291,871
382	Employment services	9.4	$ 283,115	$ 207,375	$ 387,068

Table 31: Top ten industries by employment affected by the construction and operation of a sugar beet ethanol plant in Fresno County, California.

Sector	Description	Employment	Labor Income	Value Added	Total Output
9	Sugarcane and sugar beet farming	1,826.2	$ 12,888,172	$ 38,257,906	$ 77,260,976
36	Construction of other new nonresidential structures	210.8	$ 13,434,802	$ 17,228,386	$ 38,000,000
49	Beet sugar manufacturing	179.0	$ 15,081,549	$ 19,552,074	$ 101,012,529
360	Real estate establishments	68.2	$ 1,086,199	$ 11,596,079	$ 13,775,448
413	Food services and drinking places	59.8	$ 1,167,341	$ 19,532,314	$ 3,694,966
19	Support activities for agriculture and forestry	55.5	$ 1,669,162	$ 1,630,944	$ 2,005,483
335	Transport by truck	45.5	$ 2,908,812	$ 3,445,503	$ 6,191,123
39	Maintenance and repair construction of nonresidential structures	33.8	$ 2,101,016	$ 2,717,870	$ 5,445,138
388	Services to buildings and dwellings	29.4	$ 816,206	$ 1,085,812	$ 2,082,471
369	Architectural, engineering, and related services	27.5	$ 1,710,863	$ 1,751,193	$ 3,285,008

Table 32: Top ten industries by employment affected by the construction and operation of a sugarcane ethanol plant in Imperial County, California.

Sector	Description	Employment	Labor Income	Value Added	Total Output
9	Sugarcane and sugar beet farming	2,184.90	$30,923,115	$80,581,612	$162,732,753
36	Construction of other new nonresidential structures	505.1	$28,220,833	$37,308,853	$86,706,471
49	Beet sugar manufacturing	356.1	$22,095,605	$30,989,287	$193,625,962
19	Support activities for agriculture and forestry	142	$3,878,683	$3,780,902	$4,769,709
335	Transport by truck	80	$6,043,866	$6,987,121	$11,825,880
413	Food services and drinking places	74.3	$1,474,588	$2,451,413	$4,616,577
360	Real estate establishments	49.4	$656,627	$8,262,129	$9,832,676
369	Architectural, engineering, and related services	43.8	$2,209,986	$2,274,210	$4,686,317
388	Services to buildings and dwellings	43.4	$923,796	$1,321,075	$2,774,715
319	Wholesale trade businesses	31.1	$1,997,424	$3,995,887	$4,589,156

The creation of new industrial facilities in California results in a large number of direct and indirect jobs and significant increases in economic activity in the counties where they are located and the state as a whole. In each case, these facilities are located in economically disadvantaged rural areas, populated by underserved groups. These jobs and the related social benefits to the state are a positive outcome of the development of a green economy, anticipated in the AB 32 scoping plan and both Governor Schwarzenegger and Governor Brown's objectives for the transformation of the state's economy.

Results

In-state bioenergy production from crop sources will contribute to, but not be sufficient for the state's needs for alternative fuels and power. Based on the use of readily grown crops and simpler, currently commercial conversion technologies suitable for high quality feedstocks, it is reasonable to anticipate that current in-state liquid biofuel production could increase from all feedstock sources investigated by approximately 140 Mgge/y of ethanol and biodiesel fuel, plus small additional amounts of power. The crops considered include winter annual oilseeds useful for biodiesel, energy (sugar) beets, sweet and grain sorghum, and sugar and energy cane for ethanol. There are unique opportunities for a small number of crop-based bioenergy based businesses in California supported by the exceptional, place-specific agroecological and policy conditions that prevail here. These new biofuel facilities will create approximately 350 permanent jobs. Many of these benefits would be concentrated in rural, disadvantaged communities. There are no significant adverse environmental effects anticipated from the small modifications to existing cropping systems in the state that are required for these new bioenergy businesses. Feedstock production will be sustainable based on current, broadly accepted understandings of that term. There is little risk of adverse climate consequences. Opportunities for crop-based biofuel businesses in California are overlooked in aggregated analyses and macro-scale models and require the locally adapted methods used here for assessment.

5. Technologies associated with agricultural biofuels

Traditional crop based feedstocks have several advantages that may lead to their use in California. Those that are sources of high quality substances like sugar (sucrose), starch, and oils are easily converted to a wide range of useful products at low cost and mostly use now well-known technology (Figure 26). They are easily produced, transported and stored using existing technology and infrastructure, and they are familiar to growers. If produced with high yields, as they would be in California, they will result in per acre biofuel yields equivalent to the high estimates made for cellulosic feedstocks, but at much lower initial capital and operating costs. Many of these crops already are produced or have been produced in the state and are familiar to and valued by farmers. Annual crops increase diversity in cropping systems in the state and provide greater management flexibility compared to reliance on perennials only.

To help evaluate potential feedstocks for California, it was useful to compare ethanol yields from different major sugar or starch based feedstocks and frequently mentioned cellulosic feedstock crops. Crop productivity is critical for ethanol yield, which will vary significantly with respect to local climate, irrigation, fertilizer and other agronomic conditions. The ease and cost of fuel production from different quality feedstocks also influence prospects for their use. Sommerville et al. (2010) compared average productivity, ethanol yield, water use and other requirements for several feedstocks including corn, sugarcane, Miscanthus, poplar, and Agave spp. These comparisons are included in Figure 26 and Table 33. Additional values for sugar (energy) beet have been added to this comparison for European and Californian conditions. Crops like energy (sugar) beets and sugarcane, when produced with high yields in California, have correspondingly high yields of ethanol that are achievable with current technology at lower cost than other advanced biofuel feedstocks. Cellulosic or low quality feedstock sources have been slow to enter the market, and are less likely to be produced in California. For these reasons, it is reasonable to focus on annual and short-lived perennial crops, especially with a primary intended use for transportation fuels.

Figure 26: Potential ethanol yields and technological availability for selected feedstocks.

Crops like beets can be produced in California with yields and efficiency and manufactured into fuels using current or near-term technology at yields equal to or greater than other feedstocks.

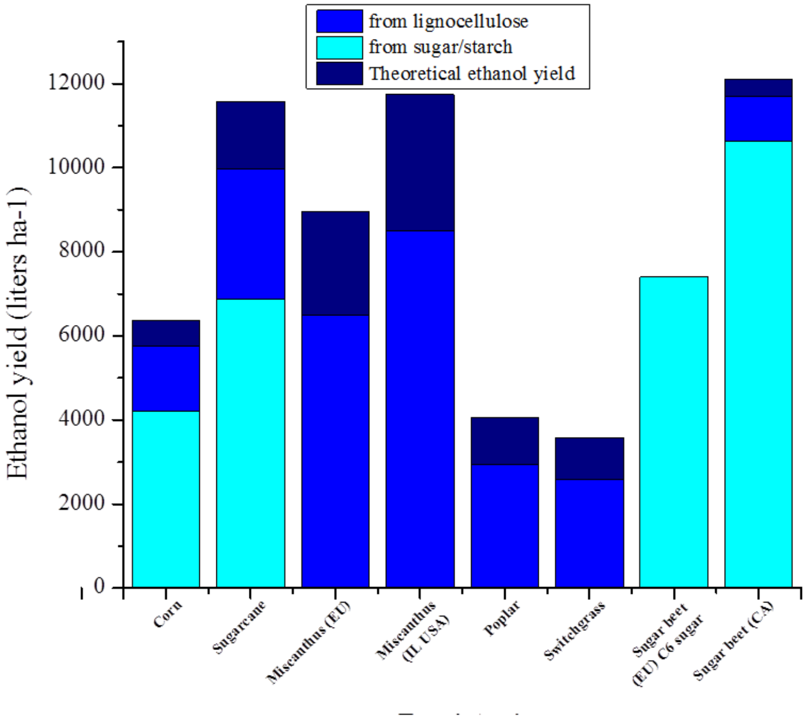

Table 33: Ethanol yield per hectare from different feedstocks.

Feedstocks for ethanol production	Range of productivity, as harvested	Average productivity	Theoretical ethanol yield	Current ethanol yield*	Theoretical ethanol yield
	MT ha^{-1} year^{-1}	MT ha^{-1} year^{-1}	L ton^{-1}	L ha^{-1}	L ha^{-1}
Corn (Average in USA)	80-300 bu/ac	160 bu/ac (est)		5748 (total)	
Stover	9	9	430	1600	2000
Sugar beet (EU) C6 sugar (Bowen et al., 2010)	74-100	69		7400	7600
Sugar beet root yield	74-100		650		7600
Sugar beet (CA)	100	100		10,000	
Sugar		16	650	9200	11,000
Non-sugar		1.6	65	940	
Sugarcane*	80	80		9950 (total)	1150
Sugar	11	11	650	6900	7100
Bagasse	10	10	440	3000	4400
Miscanthus (average in EU)	21	21	430	7100	8900
Miscanthus (IL USA)*	15-40	28	430	8500	12,000
Agave ssp.*	10-34	22		6800	
Poplar	5-11	10	390	3200	3700
Switchgrass*	8	8	350	3900	2900

Notes: In Table 33, the range and average of the productivities of different feedstocks were listed as the parameters for current ethanol yields along with theoretical ethanol yield estimates from the literature. The average productivity of corn in U.S. was set at 160 bushels per acre per year, which has 1:1 grain to stover and half of the stover was assumed harvested for ethanol production (2014). Sugar beet yields in California were 40 tons per acre (~100 tons per hectare) with the sugar content of 16.3%.

##*conversion factor derivation: (1.11 pounds of C6 sugar/pound of polymeric sugar or 1.136 pounds of C5 sugar/pound of C5 polymeric sugar) x (.51 pounds of ethanol/pound of sugar) x (2000 pounds of ethanol/ton of C6 (or C5) polymeric sugar) x (**1 gallon of ethanol/6.55 pounds of ethanol) x (1/100%)

**specific gravity of ethanol at 20ºC

http://www.agweb.com/article/2013_average_yields_158.8_bu.acre_corn_43.3_bu.acre_soybeans_NAA_AgWebcom_Editors/2014. 2013 Average Yields: 158.8 bu/acre Corn, 43.3 bu/acre Soybeans, (Ed.)

6. Life Cycle Assessment (LCA) of GHG Emissions from Agricultural Feedstock Use

Life Cycle Assessment

The use of biofuels and biopower should reduce the global warming potential (GWP) of transportation fuel use. Because fuel made from plant materials recycles atmospheric CO_2 captured by plants, bioenergy use is seen as potentially beneficial in reducing GHGs (Farrell et al., 2006; Hammerschlag, 2006; Zah et al., 2008). But a more complete analysis may reduce or eliminate that benefit (Plevin and Delucchi, 2013; DiCicco, 2013). The federal Renewable Fuel Standard (RFS) specifies minimum levels of GHG reductions for diverse types of biofuels, based on the feedstock type (USEPA, 2009). USEPA (2009) and CARB (2009) both use life cycle assessment (LCA) methods to determine a fuel's carbon intensity (CI). This alternative fuel CI is then compared to the CI of average petroleum derived gasoline and diesel. The methods used by each agency have areas of similarity, but also differ. They differ chiefly in how they assess market effects on land use. This is referred to as Indirect Land Use Change (ILUC) and embodies the economic idea that diversion of farmland and crops for bioenergy production in the United States or elsewhere provokes an increase in land use for crop production in diverse locations worldwide to meet national and global demand for those crops no longer met due to biofuel crop diversion. Carbon emissions from altered terrestrial carbon stocks (forest destruction and loss of SOM from carbon rich soils in native pastures) are released to the atmosphere and must be included with the carbon emissions of the crop-based biofuel that led to that effect. A similar effect is attributed to corn crop residue removal (corn stover) for biofuel in the US (Liska et al., 2014). Such effects and associated CI values cannot be directly measured but are artifacts (estimates) of models. They are inferred by using complicated economic models of global trade and production. Because US EPA and CARB use different models and different sets of assumptions, they come to different estimates for these values, but fuel providers in California must meet both sets of estimates to remain compliant with federal and state regulations.

A process called life cycle assessment (LCA) is also required for most sustainability standards (van Dam et al., 2008). The LCA model most commonly used in the United States is the GREET[15] model (Wang et al., 2007, 2012). Two California resource agencies, CARB and the Commission have adopted a modified version of GREET called CA-GREET[16].

Two types of LCA approaches are used. Attributional LCA (ALCA) tracks energy and material flows along a product's supply chain and during use, disposal or recycling (Figure 27 and Figure 28). Most LCA tools and studies use this approach (Plevin et al., 2013). ALCA's reflect the average operation of a static system. Consequential LCA estimates how flows to and from the environment would be affected by different decisions (Plevin et al., ibid.). Ideally, CLCA analyses are dynamic, context specific, and reflect marginal changes (Plevin et al, 2013). CLCA models are data intensive and seek to include all the significant factors in economic systems affected by the production of biofuel feedstocks and fuels, even at the scale of the world

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[15] https://greet.es.anl.gov/

[16] (http://www.lifecycleassociates.com/

economy and the world landscape. This epistemological challenge is formidable and limits the value of predictions from even the most comprehensive CLCA models. ALCA, however, may not reflect adequately the climate and other economic and environmental consequences of bioenergy production. These difficulties are inherent within and unavoidable consequences of the adoption of comprehensive policies like the LCFS and federal RFS.

Adopting the LCFS, however, is equivalent to a policy level assumption that the consequences of prudent bioenergy use will be beneficial on the whole, and implies a willingness to accept a range of associated consequences. If local land use and related environmental and social effects can be estimated for individual projects, and if these are found to be non-harmful or desirable on the whole, and if few acres of incumbent crops are likely to be displaced, then market effects are likely to be inconsequential, minimizing risks associated with indirect land use change (ILUC) as well. In that case, GHG savings from biofuels are likely to be real.

CA-GREET produces ALCA estimates, and CARB uses GTAP[17] to estimate broader effects on markets and land use (CLCA). USEPA uses different models. GREET is used for ALCA estimates, while FASOM[18], a CLCA model, is used for domestic (US) estimates of GHG, and FAPRI[19], a partial equilibrium model, is used for international effects and land use change estimation. These models are supplemented with the use of satellite imagery when possible (Lave et al., 2011). Even the most careful LCAs, however, involve assumptions and decisions about qualitative criteria used in making quantitative assessments (Zah et al., 2008). LCAs are not predictive. They do not include anticipated future conditions and technical breakthroughs, so are best used for purposes of comparison rather than for setting absolute standards.

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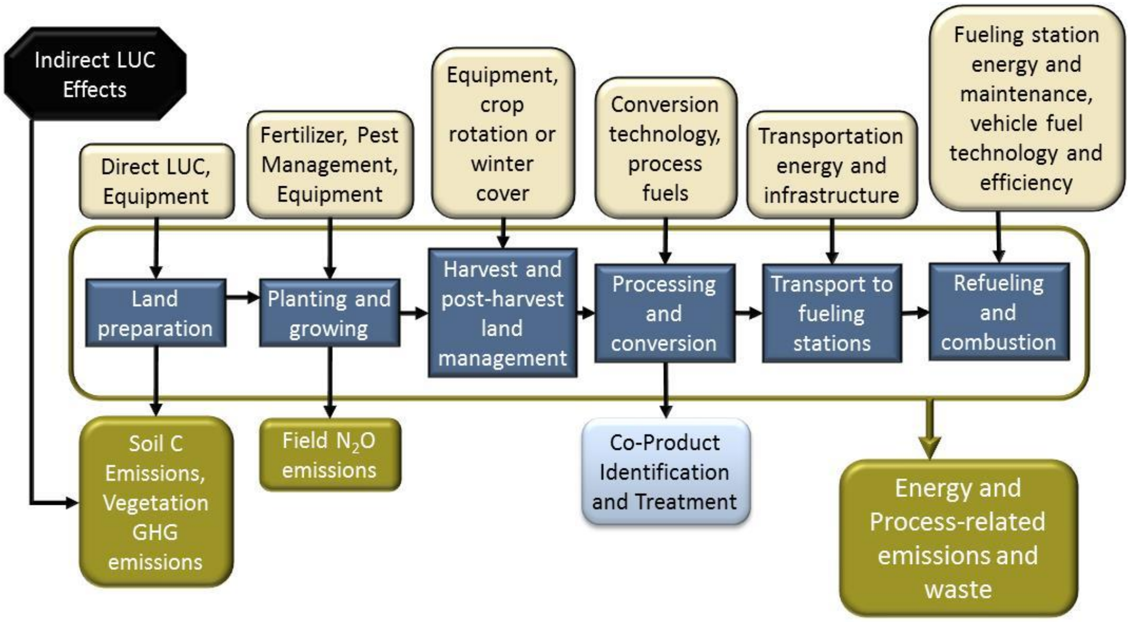
[17] https://www.gtap.agecon.purdue.edu/models/current.asp

[18] http://agecon2.tamu.edu/people/faculty/mccarl-bruce/FASOM.html

[19] http://www.fapri.iastate.edu/publications/

Figure 27: ALCA applied to biofuel life cycle assessment. ILUC values are exogenous.[20]



CARB (2013) has evaluated both canola biodiesel and sugarcane ethanol from imported sources and provided fuel CIs for these. Camelina has not been assessed because there is no current in-state production and national levels of production are modest. EPA has made a preliminary estimate for Camelina produced from dry-farmed systems in the Pacific Northwest that is lower than either soybean or canola derived biodiesel[21]. Shonnard et al. (2010) have provided an initial assessment of jet fuel and advanced biodiesel from Camelina oil feedstocks produced in the prairie regions of the United States. They reported a value of 22.4 gCO_{2eq} /MJ for the farming related costs of Camelina production and a FAME conversion pathway. EPA[22] assumes no or limited ILUC effects (equal to zero). Adding CARB's estimated ILUC value for canola to this estimate for Camelina, provides a comparable estimate of 53.5 gCO_{2eq} /MJ. There is no current approved CARB determination, however, for this feedstock and pathway to date. Camelina is qualified for support under the federal Biomass Crop Adoption Program. This program subsidizes production of selected new feedstocks and biofuel pathways. To date, it has had little effect on the adoption of Camelina in California.

Canola oil made from North American sources is given a presumptive fuel CI of 62.99 gCO_{2eq} /MJ, compared to 94.71 gCO_{2eq} /MJ for conventional petroleum diesel and 83.25 gCO_{2eq} /MJ for biodiesel from soybean oil. Of this, an estimated 31 gCO_{2eq} /MJ is from ILUC related emissions, leaving 31.99 for farming related carbon costs, transportation of feedstocks, and biodiesel conversion. If canola is produced in largely fallow winter periods in California, with higher yields and with greater RUE than elsewhere in North America, and if new crops are added to

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[20] Courtesy of Dr. A.M. Kendall, Dept. of Civil and Environmental Engineering, UC Davis.

[21] http://www.gpo.gov/fdsys/pkg/FR-2013-03-05/pdf/2013-04929.pdf

[22] Ibid.

farming systems due to canola's inclusion, then both the CI of farming related costs and ILUC values should be lower for in-state biodiesel production. An alternative land use for these oilseeds may involve their use for cover crops in winter in orchards and vineyards. Particularly replanted orchards have large amounts of fallow land between rows of young trees that may be used for crop production while the orchard (or vineyard) is still small.

CARB also has estimated the fuel CI for ethanol produced from sugarcane in Brazil. For mechanized harvests and efficient use of bagasse-derived electricity at the mill, the value from CARB is 58.6 gCO_{2eq} /MJ compared to 95.66 gCO_{2eq} /MJ for conventional petroleum-based gasoline. Of this value, 46 gCO_{2eq} /MJ is attributed to ILUC and only 12.4 gCO_{2eq} /MJ to feedstock production. More recently, CARB has proposed reducing this value to 26.5 gCO_{2eq} /MJ[23]. If farming sugarcane in California stimulated less ILUC, or even spares land from conversion in Brazil, in-state feedstock production could result in very low fuel CIs. Additional values for other feedstocks are reported in Figure 28.

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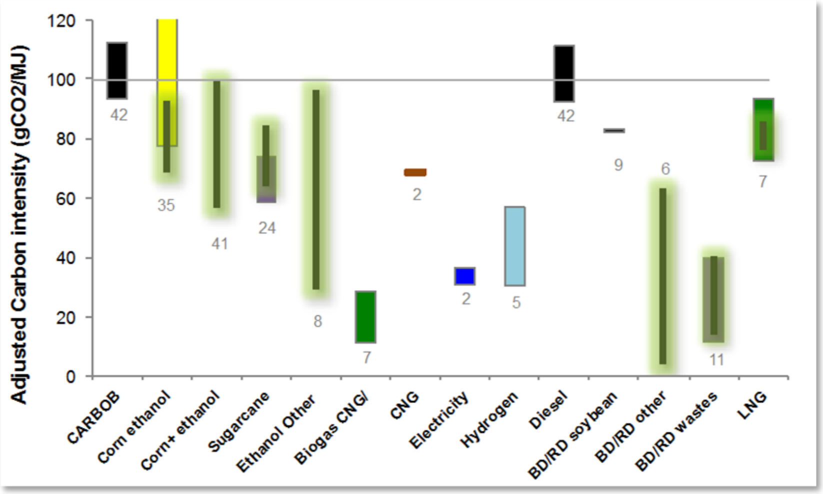
[23] CARB, March 11, 2014.

Figure 28: Carbon intensity values determined by CARB.[24]

Glowing lines represent opt-in values through the Methods 2A and 2B pathway. The horizontal line represents the default gasoline (CARBOB) and diesel (ULSD) values (not distinguished at this scale). Numbers under each bar represent the number of default and opt-in CI values for each pathway. Corn+ pathway is ethanol produced from a mix of grain-based feedstock including corn, sorghum, and wheat slurry. "Ethanol Other" includes feedstock from other grains (e.g. sorghum) or waste (e.g. waste beverage). "BD/RD Other" includes biodiesel or renewable diesel from other oil seeds or corn oil.



There are critics of the use and value of these methods. Plevin et al. (2013) and Delucchi (2012) have argued that ALCA does not support definitive determination of whether a particular biofuel or bioenergy project actually reduces GHG emissions in a meaningful way when all possible direct and secondary interactions are included. They suggest that the values used by CARB and US EPA may not have any real connection to reduction of the impact of CO_2 emissions from transportation using those fuels on rising global temperatures.

Selected California Feedstocks (Literature Values)

ALCA based estimates from a range of sources of the potential fuel CI for the crops produced here are reported in Table 34. Many feedstocks and processes support fuel CI levels in the 10 to 30 gCO_{2eq} /MJ range. Depending on how ILUC values are calculated and allocated, these fuels may find uses in California. Under the current regulations governing the use of alternative fuels

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[24] Some opt-in values can be lower than the default values in a particular pathway due to differences in the designed vs. actual technologies used. CI values are adjusted with an energy efficiency ratio (EER) of 3.4 for electricity and 2.5 for hydrogen (gasoline displacement). There are a large number of pathways approved or in review for many of these feedstocks that reflect local differences in the energetic costs of production and fuel manufacture. Yeh and Witcover, 2014. Used with permission. http://www.its.ucdavis.edu/research/publications/publication-detail/?pub_id=2008

in California, only fuels with low CI values, calculated using the CARB methods, will find a place in markets in the state. Low CI feedstocks may also be more valuable than higher CI feedstocks. The fuels made from low CI sources will support a higher price in the market and may support a higher price for such feedstocks, increasing the incentive to reduce GHG intensity in feedstock production and allowing companies to acquire more feedstock in the process.

Table 34: Summary of literature values of carbon intensity (CI).

Crop	Source	Country	g CO_{2eq}/MJ	ILUC accounted?	ILUC estimate	Fuel CI
Oilseeds						
Canola	USEPA	USA	45.46	Y	39.36	74.82
	CARB	USA	31.99	Y	31	62.99
	IEU	Germany	49.7	N		
	(S&T)2	Canada	5	N		
	(S&T)2	Europe	21	N		
	de Vries	Netherlands	45	N		
	Lund University	Sweden	26.4			
	Resources Conservation & Recycling	Europe	260			
	FEAT-Penn State	USA	41	N		
Camelina	CARB	USA	7.58	Y	0	7.58
	(S&T)2	Canada	21.3-30.3	N		
	USEPA	USA	36.9	Y	0	36.9
Pennycress	Michigan State University	USA	28.4	N		
Sugar Crops						
Sugar Cane	USEPA	USA	36.66	Y	4	40.66
	CARB	USA	12.4-27.4	Y	46 (26.5*)	62
	IEU	Germany	15.3	Y	34.4	49.7
	Lund University	Sweden	17.6			
	Resources Conservation & Recycling	Europe	48	Y		
	Machedo et al.	Brazil	21.3	N		
	Unica	Brazil	29	N		
	California Ethanol & Power	USA-CA				
Sugar (energy) beets	USEPA	USA	n/a			
	CARB	USA	n/a			
	IEU	Germany	37.7	N		
	de Vries	Netherlands	50	N		
	Lund University	Sweden	16.9	N		
	FEAT-Penn State	USA	16	N		
	UC Davis/Mendota	USA-CA	27.5	N		
	Tracey Renwables	USA-CA	22(-81)	N		
Grain/Starch Crops						
Grain Sorghum	Cai et al., 2013	USA	50	N		
	USEPA	USA	38.2	Y	28.8	66.98
	CARB	USA	66.24	Y	30 (17.5*)	96.24
	Western Plains	USA	73.3-74.9	Y		
Celluloisc crops						
Energy Cane	USEPA	USA	16	Y		
	Canergy	USA-CA				
Giant Reed	USEPA	USA	10	Y		
Switchgrass	USEPA	USA	12	Y		
Notes	CARB estimate, 2A2B pathway					
	CARB estimate, standard pathway					

Notes:

* Indicates 2014 data, Medota estimate basedon Alexiades (2014) and uses multiple feedstocks

http://www.arb.ca.gov/fuels/lcfs/workgroups/workgroups.htm#pathways

http://www.arb.ca.gov/fuels/lcfs/lu_tables_11282012.pdf

http://www.arb.ca.gov/fuels/lcfs/regamend13/Draft_Crude_CI_Values_%28OPGEEv1.1_DraftA%29_March_4_2013.pdf

http://www.epa.gov/otaq/fuels/renewablefuels/new-pathways/rfs2-pathways-determinations.htm

http://www.ifeu.de/index.php?bereich=nac&seite=ENZO2

7. Potential for Biofuel Production in California.

Opportunities

There are four larger scale ethanol production facilities operating in California, and thirteen smaller-scale biodiesel facilities[25]. The ethanol facilities use corn grain and more recently grain sorghum and each produce approximately 60 mgy. California's current fuel ethanol use is approximately 14.6 billion gal per year[26]. Nearly 10% of that amount is ethanol blended to increase fuel octane levels and to comply with LCFS, so demand for ethanol in the state is approximately 1.46 bgy, far in excess of that produced by the state's three significant facilities.

The biodiesel facilities in California are smaller and vary in size considerably. They use waste fats, oils and grease and some use vegetable oils and produce about 50 mgy collectively, though actual production is variable. Demand for biodiesel due to the LCFS and RFS is much larger. Diesel fuel use in California in 2012 was 2.65 bgy. Blended with 5% biodiesel, demand could be as large as 130 mgy, greater than in–state supplies to date. Higher blending rates are possible with current infrastructure and used in some instances and would further increase total demand. Currently, most biofuel used in California is imported, primarily from corn ethanol refineries in the mid-western United States and out-of-state biodiesel producers. Increasing amounts of sugarcane ethanol are being used as well, due to its estimated lower Carbon Intensity than corn ethanol according to CARB[27]. There is sufficient demand to support in-state businesses, which would increase direct employment and investment in California, if economically competitive bioenergy businesses can be developed.

Based on the case studies included here, and under favorable assumptions about crop yields, water availability, and the availability of capital for biorefinery construction, the potential for in-state fuel production under favorable circumstances for all enterprises amounts to approximately 190 Mgge/y for new sources, and an additional 25 Mgge/y for in-state grain sorghum feedstocks, which replace use of imported corn grain, without affecting total biofuel supply (Table 35). The use of grain sorghum by the state's three existing ethanol companies would not increase in-state production, but substitutes feedstocks (sorghum for corn), with approximately equivalent fuel output. There are other firms attempting to develop new sources of fuels that are not considered here. For example, fuels made from biogas from diverse sources, a second energy beet enterprise in the Delta region with a production target of 30 to 40 Mgal/y of ethanol, and others that may not have made public announcements of plans. Most of these firms claim fuel CI values in the 20 to 30 g CO_2eq/MJ range, approximately equivalent to the most efficient values reported for Brazilian sugarcane, (minus ILUC), which would likely be the principal economic competitor for in-state biofuel production. A large value for ILUC GHG effects added to in-state fuels would act as a barrier to in-state production, but we argue here

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[25] http://biomass.ucdavis.edu/tools/

[26] http://www.boe.ca.gov/sptaxprog/reports/MVF_10_Year_Report.pdf

[27] http://www.arb.ca.gov/fuels/lcfs/121409lcfs_lutables.pdf

http://www.arb.ca.gov/fuels/lcfs/2a2b/internal/mixed-feedstock-bd-071312.pdf that ILUC effects will be close to zero for the types and scale of feedstock production considered likely in the near term in California (ten years) based on agriculturally derived feedstocks.

Table 35: Estimate new biofuel volumes and in-state prices for likely biofuel feedstocks and fuels for near to mid-term biofuel production in California.

Crop	Commodity	Current Price (2013-14)	BCAM entry price (2012)	Location with most likely adoption	Estimated acres (thousands)	Fuel type	Yield (as harvested)	Feedstock cost			In-state potential	Assumptions#			
	$/t	$/t	$/t				gal/t	$/gge	gge/ac	gge/t	Mgge/y	lb/ac	t/ac	Quality	By-products?
Canola	seed	475	381	SAC, SJV	274	biodiesel	129.15	2.82	270	135.22	74.1	2500	1.25	43% oil	oil seed meal/glycerin
	meal														
Camelina	seed	340*	681	SAC, SJV	106	biodiesel	70.2	9.27		73.5	6.23	1600	0.8	32% oil	oil seed meal/glycerin
	meal														
Sorghum	grain		134-139	SAC, SJV	100	ethanol	110.95	1.81-1.88	296	73.97	29.59	8000	4		
	sweet (sugar)*		23.75	SJV, IV	15	ethanol	21.54	1.65		14.36	8.62		40	13% brix	
	lifestock feed														DDGS feed
	biogas					CNG									biogas
Beets	sugar**	65	65	SJV, IV	60	ethanol	25.2	3.87	672	16.8	40.32		40	16% sucrose	biogas, water, fertilizer
	livestock feed														biogas, water, fertilizer
	biogas					CNG									biogas, water, fertilizer
Sugarcane	sugar***		45	IV	60	ethanol	21.54	3.13	646	14.36	38.78		45	13% brix	power, biogas, water, fertilizer
	bagasse					electricity									power, biogas, water, fertilizer
	biogas					CNG									power, biogas, water, fertilizer
Energy cane##	bagasse		45	IV	40	ethanol	63-79.2	0.85-1.07	622-781	42-52.8	31.9-40.1		45###		power, biogas, water, fertilizer
	biogas					electricity									power, biogas, water, fertilizer
Sum					640						189.02				
(new supply)					536						205.66				

Waste Resources

There are several waste resources that currently are used for biofuels, or could be used for biofuels under favorable policy conditions. Waste oils and tallow, called FOG (fats, oils and greases) currently make up the majority of feedstock for the state's biodiesel industry. Currently, approximately 60 to 65 mgy of biodiesel is being produced in CA largely from in-state FOG sources. In spring of 2015, Alt-Air incorporated has started a large facility that will increase in-site capacity to approximately 100 mgy. Witsee (1998) estimated the amount of yellow grease (waste cooking oil, trap grease, and some tallow) available in different jurisdictions across the United States. The national average was 23 lb of per person per year. Sacramento was the CA jurisdiction analyzed and had a lower amount available (14 lb). Using these two values, between 60 and 100 mgy of biodiesel could be made form waste materials in the state. The large amount corresponds to informal estimates from professionals involved in the state's biodiesel industry as a likely upper bound for feedstocks including rendered animal fats. Animal fats have other uses than for biodiesel, including for livestock feeds and pet foods so not all materials from these sources will be available for biodiesel conversion unless fuel prices were to rise substantially higher than currently foreseen by EIA and other observers.

For the state's domestic biodiesel industry to grow, additional waste feedstocks will have to be imported (depriving other jurisdictions of these feedstocks), vegetable oil will have to be imported (palm oil from Indonesia or Malaysia, canola from Canada or Australia), or some oilseeds must be produced in-state for biodiesel. Currently, the cost or value of the oil in an oilseed crop like canola is higher than the cost of FOG.

Manure-based bioenergy production[28]

Biogas made from anaerobic digestion systems can be conditioned (Eng et al., 2015) and used for compressed natural gas. One of the largest sources of residual biomass in California from agricultural sources is dairy manure. Large populations of cows are located in the San Joaquin Valley, especially the southern San Joaquin Valley and near Merced (Figure 29). Populations of cows in these regions may exceed 3000 animals per square mile. One of the consequences of such large cattle densities is a tendency for excess nutrients to accumulate on farms that are applied in excess of crop needs, resulting in ground water pollution (Figure 30). Some of these nutrients might be concentrated into organic and conventional fertilizer products and sold to other users, reducing nutrient loading on farms. Anaerobic digestion systems that reduce methane losses from current manure storage systems and generate bioenergy of compressed natural gas fuels might also facilitate the creation and sale of new fertilization materials that can be used on other farms.

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[28] Based on Williams et al., 2015; Ong et al., 2015, and Kaffka et al (in progress)

California is home to the largest and likely most efficient dairy industry in the US, concentrated principally in a few areas in the San Joaquin Valley. Abundant by-product feeds from the state's diverse agricultural industries, high quality forages, mild weather and low rainfall levels make California an ideal location for large-scale dairy production systems, but co-located farms and regionally high concentrations of livestock lead to difficulties in optimally managing manure (Chang et al., 2003; Harter and Lund, 2012). Air quality problems in the San Joaquin Valley where most dairies are located mean that fugitive emissions of short-term climate pollutants originating from dairies (Chang et al, 2003; Horwath and Burger, 2013; Rochette et al., 2008; van Groenigen et al., 2004) like CH_4, N_2O, and volatile organic compounds (VOCs) exacerbate the region's significant difficulties meeting federal clean air standards. With the adoption of the Global Warming Solutions Act (AB 32), the state is implementing an aggressive policy to reduce greenhouse gas (GHG) emissions to historically low levels. Fugitive emissions of CH_4 and other trace gases from dairies (short lived climate pollutants-SLCPs), especially from current manure management systems, are regulatory targets for reduction, but regulations without cost-effective solutions will result in significant economic losses to the state's dairy industry.

Anaerobic digestion (AD) systems that might be used to process most of the manure on larger-scale dairy farms can collect methane (as biogas), reducing fugitive CH_4 emissions compared to uncovered lagoons and other handling systems by 60% or more, and create more consistent post-digester residuals for management of manure nutrients, salts and water (Burke, 2001; De Vries et al., 2012; Van der Meer, 2008; Walsh et al., 2012; Williams et al., 2015). The production and sale of bioenergy as biogas or used as transportation fuel (CNG) can help pay for the costs associated with AD systems while achieving many important public goods, including maintaining economically efficient dairy farms, creating green jobs, and supporting the state's climate change goals.

Figure 29: Dairy animal concentration in California. There are some 1.78 million dairy cows in California (milking and dry adult) and about 1.5 million support animals (calves and heifers) on about 1,650 dairies. In the central valley, there are 1,350 dairies and 1.61 million dairy cows, primarily in the San Joaquin Valley (CDFA, 2012, & CARB, 2014). Most of the dairy animals and dairies are concentrated in the San Joaquin Valley.

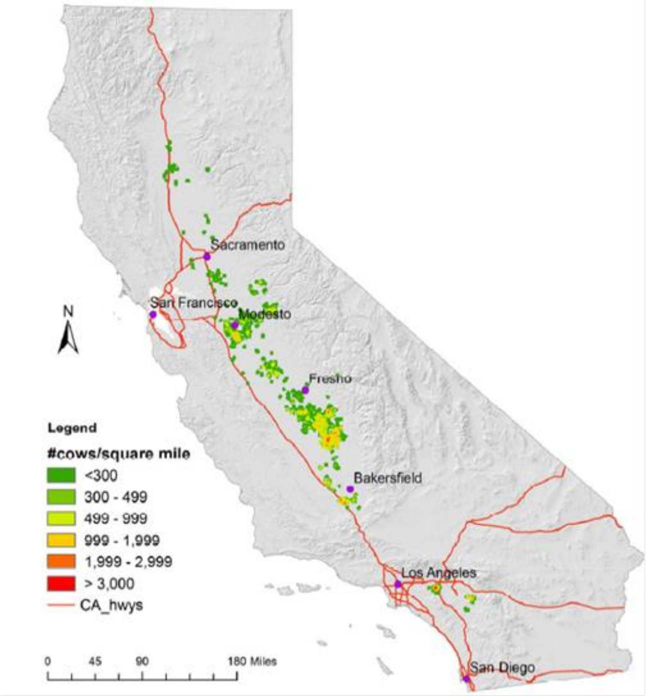


Figure 30: Nutrient surpluses calculated on a mass balance basis indicating oversupply in the Tulare region (Harter and Lund, 2013).

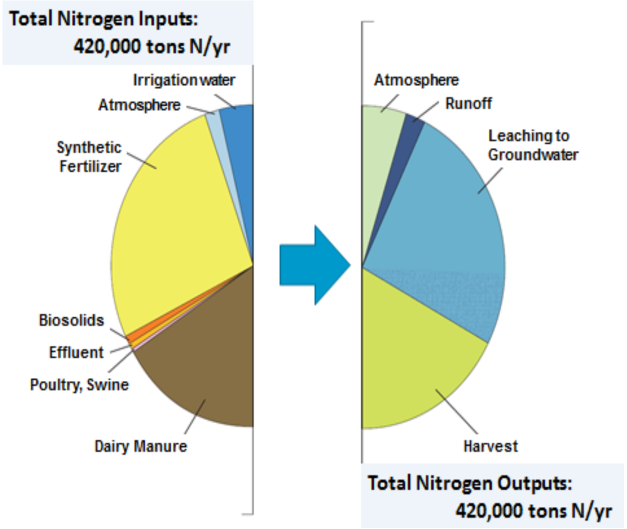
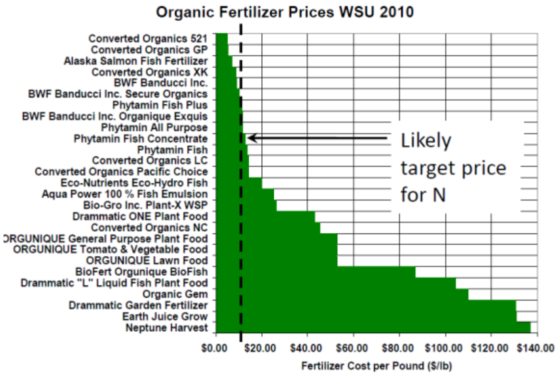


Figure 31: Many organic fertilizers are sold at a high price per unit of N. New supplies derived from AD digestates will make organic farming more economic. Jenner, 2011.



Bioconversion Systems

Agricultural Waste and Manure Digesters[29]

Although farm-based digesters have been encouraged in Europe, they are still relatively rare in the US. California has approximately 11 operational manure digester projects and 10 that have been shut down, primarily due to economic reasons (California Biomass Collaborative). Renewed public policy interest in digesters and public support for their development should lead to an increase in the numbers of digesters built in California[30].

Digesters can be designed as standard complete-mix tanks, plug-flow basins, or covered lagoons. The different designs will affect the hydraulic retention time, digestion efficiency, cost, and physical footprint of the system. Design selection is typically based upon limiting factors such as available land area and total volume requirements, but can sometimes depend on preferences and judgments of project developers.

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[29] From Ong et al., 2015.

[30] http://cdrf.org/wp-content/uploads/2014/12/DairyDigesterDevelopmentFramework.pdf

Figure 32: Complete-mix tank (top left), plug flow (top right), and complete-mix lagoon (bottom) anaerobic digesters.

Photo Credit: US EPA (2014d)

Animal Manures

Total cattle numbers in California exceed 5.4 million head, with 1.78 million milking cows (lactating and dry combined), 620,000 beef cows, and 3 million other cows (replacement heifers and calves) (R. Williams, work in progress and CBC). The manure from most non-poultry livestock falls on pastures and only confined, lactating dairy cattle manure is readily collected and potentially of use in AD systems at the current time in California. This equals approximately 6.1 million BDT/y.

Net efficiencies for animal manure bioconversion systems are calculated on the basis of the biodegradability of the volatile solids fraction of the biomass. Theoretical yield of biogas was assumed to be 12 ft^3/lb of VS destroyed (0.75 m^3 kg^{-1} of VS destroyed). Methane content in biogas from manure systems was assumed to be 60%. Biodegradable fractions for animal manures vary from 0.45 for cattle to 0.76 for poultry (Table 36).[31] Resulting power generation per animal ranges from about 1 We for chickens to nearly 190 We for dairy cattle (Table 36).

Coarsely estimated, 50 % recovery of all dairy manure on farms may be possible and the biodegradable fraction of this manure is 0.45. Net efficiencies for animal manure bioconversion systems were derived on the basis of the biodegradability of the volatile solids fraction of the biomass. Altogether, there are 1.4MM BDT of dairy manure available for digesters that could produce 2.8 billion cubic feet of biomethane (CH_4) (Williams, work in progress).

Table 36: Biodegradability and overall conversion efficiencies for animal manures. [32]

Estimated biogas potential from dairy manure in California				
Animal type	Number	wet manure	Fermentable solids (VS)	Biogas potential
		(BDT/y)	(BDT/y)	(MM cu. ft/y)
Dairy cows	1780000	6,100,000	1372500	33329610
Replacements	3055000	3,340,000	1503000	(132 MMgge)
	subtotal	9,440,000	2875500	

AD systems to process dairy manure have the benefit of converting CH_4 (with 25 times the global warming potential of CO_2) to CO_2, improving the performance of manures used on farms, replacing conventional fertilizers, and producing alternative energy [4, 13, 42, 44, 45].

Potential power and transportation fuel energy equivalents from AD systems on farms will depend on the number established, and the amount of manure collected and digested in these systems, and whether or not co-digestion occurs. Maximum production levels were estimated by Williams et al. [45]. AD system adoption will be gradual over time so potential amounts of energy will be estimated based on scenarios for rates of adoption and examples from cooperators systems. Initially, larger scale dairy systems likely will be early adopters, especially those located in high cow density regions.

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[31] Loehr, R.C. 1984. Pollution control for agriculture. Academic Press, Orlando.

[32] Dairy cows equal lactating and dry cows only. Theoretical yield of biogas was assumed to be 12 ft^3/lb of VS destroyed (0.75 m^3 kg^{-1} of VS destroyed). Biodegradable fractions for animal manures for cattle manure is 0.45. Methane content in biogas from manure systems was assumed to be 60%. CNG estiames is based on 50% of all manure from lactating and dry cows converted to CNG under optimistic conditions, at least in the near-to-mid-term. Alternatively, resulting power generation per dairy cow is nearly 190 We. Not all farms will install AD systems or can install AD systems. Other means of managing methane emissions are possible Source: ASAE D384.2 MAR2005 (R2010), Manure Production Characteristics. American Society of Agricultural and Biological Engineers, St. Joseph, Michigan.

Anaerobic Digestion of Rice Straw in the Sacramento Valley[33]

The other larger-scale agricultural residue available in California is rice straw. Currently, rice straw is incorporated following harvest into fields, where it decomposes, mostly under anaerobic conditions, creating methane. Removing rice straw and using it for a feedstock for AD systems would reduce fugitive methane emissions from rice fields by reducing the carbon source for methanogenic bacteria common in flooded rice soils. The methane from AD systems could be used to dry rice in the fall and compressed for transportation fuels, while water and nutrients could be recycled directly back to fields, and solid residues composted and reused. Kaffka et al., (2012) estimated the cost and yield of using apportion of rice straw for this purpose.

Rice production is a major agricultural land use in the Sacramento Valley with approximately 500,000 acres cultivated annually. Two million tons of rice are produced annually, with and output value of $1.8 billion and resulting in 12,700 jobs annually to the California economy.[34] Rice straw and hulls produce a significant amount of agricultural residues in the state. They are relatively consistent in quality and located within a well-defined region of the Sacramento Valley. These properties, and the current lack of profitable alternatives for the use of this large quantity of annual material, make rice straw and hulls appealing as a feedstock source for biopower or fuels. Winter flooding of rice field provides valuable habitat for water fowl and other wildlife species, creating at the same time conditions for the evolution of methane from those fields. Production of rice during the warm season is the primary source of methane emissions from the rice system, enhanced by the incorporation of large amounts of straw residues into soils, which provide the carbon source for methanogenic organisms.

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[33] Based on: Kaffka, S. Jenner, M., Liles, G., Wickizer, D., and Williams, R. 2012. Biomass Management Zones and New Pathways to Bioenergy. Draft Report. California Energy Commission, publication no CEC-500-2012-xxx. Submitted. http://biomass.ucdavis.edu/files/deliverables/3-2-1-1-energy-crops-and-residue-assessment.pdf

[34] Economic Contributions of the US Rice Industry to the US Economy. James W. Richardson and Joe L. Outlaw. Agricultural & Food Policy Center, Texas A&M Univeristy. College Station, TX. AFPC Research Report 10-3. August 2010. http://www.calrice.org/pdf/RR-10-03-Economic+Contributions+of+the+US+Rice+Industry.pdf.

The passing of the Rice Straw Burning Reduction Act of 1991 mandated reductions to the practice of open field burning of residual rice straw in the year 1992 to no more than 25 % of an individual farmers planted land, or a maximum of 125,000 acres within the Sacramento air basin, annually. This bill also scheduled a complete phase out of this straw management practice by the year 2001 with limited exceptions for disease outbreak, handled through a petition process. This act created a major shift in rice straw management to soil incorporation instead of burning, and initiated investigation into conversion technologies to transform straw into biopower and biofuels and other products. The chemical properties of rice straw, primarily its high silica content, provide a unique set of conditions that make it resistant to decomposition and limit its value as livestock feed. Rice plants accumulate silica and other cations in their tissue and may have as much as 13 percent ash content, which limits its use as forage and also as a fuel in thermal conversion technologies.

Current Straw Management Practices

The primary, current cultural practice is to incorporate most straw residue into the soil for decomposition. Straw incorporation in rice fields in California may improve soil fertility and increase soil carbon (C) storage. Another benefit of incorporation is retention of straw nutrients in fields which are primarily potassium (K) and phosphorus (P). Decomposition of rice straw occurs slowly under typically saturated winter soil conditions. When combined with flooding for rice production during the growing season, the potential for additional methane production is increased compared to straw disposal through burning.

Rice Production in the upper Sacramento Valley

The Butte Sink region includes a major portion of California's 550,000 acres of rice production.[35] Butte, Colusa and Glenn Counties represent 60 percent of total statewide rice acreage. Anaerobic digestion systems are most likely to be first located in areas with high concentrations of consistent biomass resources so an emphasis is placed on this three county area. This crop has a strong economic influence on these counties, but prices can vary widely, suggesting income from a supplemental enterprise using rice straw would be beneficial (Figure 33, USDA-ERS, 2011). Recent Butte County average yields are 4.7 ton/acre of rice (Price, 2010). An approximately equivalent amount of straw is produced but not all straw can be collected practically. Rice produces straw yielding about 3 tons per acre (Schuetzle, et al., 2008b; Williams, et al., 2008.). However not all of this straw is available for use. Schuetzle, et al. (2008b) estimate 2 BDT of rice straw per acre are available. Williams et al (2008), estimate that only 1.5 BDT are technically available for utilization. The central Butte Sink region would provide approximately 1,000,000 tons (500,000 dry tons, Table 37) annually. Based on an estimated energy content of 5,960 Btu/lb for rice straw, the Butte Sink could provide 5,970,700 million btu (MMBtu) of standing rice straw energy, and nearly 3 million MMBtu of energy embodied in the available dry straw.

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[35] The Butte Sink Sub-inventory Unit (SIU) covers an area of about 10,300 acres, bordered by the Biggs/West Gridley SIU to the north and east, Sutter County to the south, and Butte Creek (the Colusa County boundary) to the west. the Butte Sink area includes many waterfowl refuges and privately

Figure 33: Average annual price received by Californian rice producers (2002-2011).

Table 37: Annual gross and available rice straw by county in the core Butte Sink region.

County	Rice Acreage	Rice Straw (Gross tons) 3tons/acre	Rice Straw (available tons) 1.5 tons/acre
Butte	103,400	310,200	155,100
Colusa	141,000	423,000	211,500
Glenn	89,500	268,400	134,300
Total	333,900	1,001,600	500,900

Fine-textured, formerly wetland soils dominate in this area and are particularly well-suited for rice cultivation. Sufficient water has been available from the Sacramento River and secondary streams in the region that formerly created permanent and ephemeral wetlands in pre-settlement times, though supplies have been curtailed during the recent drought.

Combustion of Rice Straw

Most previous analyses of rice straw and hulls have focused on combustion for power generation. Two biomass power facilities already exist within the rice growing region located within the Oroville BMZ. But rice straw is a problematic feedstock for combustion (Jenkins and Bakker, 1996). It is very high in biogenic silica, and contains large amounts of K and chlorine (Cl), which lead to problems with combustion (slagging) due to the low melting point of this silica or emission exceedances. There are modest amounts of nitrogen (N) in the straw. The Wadham Energy biomass power plant in Williams operates exclusively with rice hulls, not

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managed wetlands habitats. https://www.buttecounty.net/Water%20and%20Resource%20Conservation/BMO/~/media/County%20Files/Water%20Resource/Public%20Internet/BMO/2011%20BMOs/DRAFT_ButteSink_11_BMO.ashx straw. It is a 25 MW, suspension-fired (as opposed to fluidized bed or grate-fired boilers) steam cycle power plant.

One suggestion has been to leave rice straw uncollected in fields overwinter to allow for leaching, and then to collect it for combustion. But degraded straw is expensive to collect and equipment for doing so has not been optimized. Straw yields are more variable in the spring than in the fall and lower (Jenkins and Bakker, 1996; Bakker, et al., 2002; Bakker and Jenkins, 2003). Removal in spring could also interfere with timely planting operations during critical planting periods in spring and be difficult to bale under dry enough conditions for storage. Processing baled rice straw will use large amounts of water and be expensive. All programs that remove rice straw also remove nutrients that must over time be replaced through fertilizer applications. Doberman and Fairhurst (2002) report that about 40 percent of the N, 30 percent of the P, and 80 percent of the K taken up by the crop remains in the straw. Removing 1.5 ton/acre of rice straw would also remove 22 lb. of N, 49 lbs of K and 2.8 lbs of P per acre per year (Nader, 2009).

Ethanol from Rice Straw and Thermochemical Conversion

Schuetzle et al (2008) analyzed the production of ethanol from rice straw and estimated that 72-80 gallons per ton (gal/ton) could be produced thermochemically or 59 gallons per ton biochemically. There are many differing estimates of such yields but few processes operating at sufficient scale for certainty (NRC, 2011). The most comprehensive recent analysis of the potential to produce ethanol from celluosic materials, particularly *C4 perennial grasses*, found that the most reasonable value to use for such estimates is 70 gal/ton of dry matter (DM; NRC, 2011).[36] Rice straw is much higher in ash than perennial grasses, so a lower value is more likely. Using 60 gal/ton, 1 million tons of rice straw would produce up to 60 mgy of ethanol if an effective and economic commercial process could be developed.

There have been a series of research projects focused on rice straw and ethanol for nearly two decades. Funding for a project to be located in Gridley was provided by CEC, USDOE and USDA. The first project, in the mid 90's, evaluated enzymatic hydrolysis technology (DOE through NREL) and then acid hydrolysis. Eventually, gasification technology was considered by NREL for the Gridley project. Several private firms were engaged in this project (Schuetzle et al., 2008). In 2005, the National Renewable Energy Laboratory (NREL, 2005) published an analysis carried out by TSS, Inc. of a proposed project to convert rice straw to ethanol using a biomass gasification technology created by Pearson Technologies, Inc. A 20 mgy facility was envisioned. The Pearson Process was purported to use a proprietary combination of steam reformation and gasification to create syngas, electricity and ethanol from biomass. A Fischer-Tropfsch (FT) process would create a liquid fuel from the synthesis gas generated by gasification of rice straw. Tests were carried out on a pilot facility in Mississippi owned by

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[36] C4 grasses are very efficient, carbon-capturing plants. These are cultivated grasses such as corn, sugarcane, sorghum, switchgrass, and miscanthus. C3 plants which are more common, but less efficient at utilizing carbon include wheat, canola, and Sugarbeets. Of all of these plants listed only switchgrass and miscanthus are perennial grasses that grow multiple years without reseeding.

Pearsons. The high ash content (primarily silica) and the physical difficult of handling rice straw presented obstacles in these tests. These physical characteristics of rice straw limit any efforts to transform the straw's carbon into energy (Jenkins and Bakker, 1996). All of these previous efforts have failed to result in operating facilities or energy production in any form, and have raised public concerns, including a grand jury investigation by the Butte County Grand Jury.[37]

Methane Emissions from Rice Fields

Rice is a unique plant that is adapted to saturated (flooded) soils. Prolonged saturation results in anaerobic conditions and the emission of methane (CH_4), a greenhouse gas 25 times more potent than carbon dioxide (CO_2).[38] It is estimated that 20 percent of all *anthropogenic* CH_4 emissions come from wetland rice production (Bossio et al 1999).[39] The ultimate sources of the carbon that is transformed into CH_4 are the rice straw and roots that are incorporated into the fields after harvest. Since straw burning is now limited, the potential for methane emissions from rice production in California has increased due to public policy. An important benefit of rice straw removal and utilization in a bioenergy system is the reduction of greenhouse gases (in this case CH_4) emitted from rice fields, considered a short lived climate pollutant.

Bossio et al (1999) estimated that 9.2 g) Cm^2 as CH_4 is emitted during the spring from a field that has had rice straw incorporated. Fitzgerald, et al., (2000) provided different estimates from work carried out in fields in California in various time periods. In his work, the low value reported for CH_4 emissions from incorporated rice straw is 13.1 g CH_4/m^2 and the high was 27.3 g CH_4/m^2. The comparative values for burned rice straw CH_4 emissions reported by Fitzgerald, et al., (2000) were 5.2 g CH_4/m^2 and 5.7 g CH_4/m^2. The California Energy Commission (CEC, 2002), following the IPCC protocols, and adapting a variety of California study results, identifies 12.2 g CH_4/m^2 as the appropriate annual source of methane emissions averaged across all practices (including burned and incorporated).[40] Using the CEC value of 12.2 g CH_4/m^2, converting to acres and multiplying by the 334,000 acres of rice in the Butte Sink region, yields a total annual methane emission of 16,500 Mg CH_4. This value serves as a reference point from which to reduce methane emissions from rice straw.

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[37] http://www.buttecounty.net/GrandJuryDocs/BCGJ_Final_Report_FY10-11.pdf

[38] Intergovernmental Panel on Climate Change (IPCC), Direct Global Warming Potentials. Climate Change 2007: Working Group I: The Physical Science Basis. http://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch2s2-10-2.html. It is noteworthy that this Global Warming Potential (GWP) of 25, changes over time beginning as GWP of 21in the 1995 second assessment, then 23 in the 2001 third, and now in the 2007 assessment, is 25. This CH_4 GWP changes over the target horizon (i.e. 25 year vs. 100 years).

[39] *Anthropogenic* refers to emissions that are derived from man-made activities.

[40] It is noteworthy that these rice straw emission levels are highly variable across practices and seasons. Even the units in which the emissions are reported (seasonal vs. annual, or carbon vs. methane).

Using Rice Straw for Production of Biogas in Anaerobic Digestion Facilities

An alternative idea is to collect straw in fall, while still moist, ensile it similar to corn silage, and then use it as a feedstock with other readily available biomass materials collected in the region and co-digested in anaerobic digestion (AD) systems. Large-scale silage making campaigns are common in agriculture but have not been attempted with rice straw before. Nader (2009) reported higher rates of *in vitro* gas (biomethane) production under controlled conditions from fresh (moist) versus dried rice straw.[41] Their tests do not replicate gas production from ensiled rice straw or from mixtures of rice straw and more highly fermentable organic residuals that might also be produced for co-digestion during winter months in rice areas, but do indicate that AD fermentation is possible. Alternatively, dry rice straw can be bailed and stored, and then rewetted when added to a digester. Water used in AD processes is largely recoverable.

Anaerobic Digestion Technology

AD is a mature technology with several companies providing engineered systems. It is a biochemical conversion pathway and can utilize a wide range of organic materials. The products produced are biogas, water, nutrients, and recalcitrant organic materials, enriched in lignin. Residual, highly lignified materials might be used subsequently for combustion or thermochemical processes because of their increased energy density compared to the original biomass. Zhang and Zhang (1999) found that digestion reduced levels of K, Cl, and S, and that preliminary combustion of digested rice straw did not show signs of fouling even at higher temperatures. Alternatively, given the large amount of biogenic silica in the rice, residues could be used for animal bedding, composted, or spread on fields directly. Anaerobic digesters are readily scalable and could be located strategically in the rice production areas, perhaps near rice drying facilities, to allow for short feedstock transport distances. Existing rice driers are strategically located throughout the rice producing region and already operate on natural gas. Biomethane from rice straw digesters could offset or replace this natural gas use and be sold offsite when driers are not in use via pipeline injection, or compressed for fuel as CNG. Purified methane could be compressed and used to power trucks, similar to the use for biogas at the Hilarides dairy near Lindsay, California[42]. Water, nutrients, and organic residues and minerals in effluent from the digester would be returned locally to surrounding fields, since the facility would be located within the feedstock supply region. If methane were captured from rice straw in AD systems, fugitive methane losses would be reduced from rice fields compared to current management. Biomethane supplies would become available within the BMZ. The use of AD holds promise to address disposal and management issues associated with rice straw in the Sacramento Valley (Zhang and Zhang, 1999). Rice straw can produce renewable bioenergy in

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[41] *In vitro,* here, refers to anaerobic digestion studies which looked at rice straw digestion in isolation.

[42] Biomethane Fuels Dairy Fleet. BioCycle. June 2009, Vol. 50, No. 6. http://www.phase3dev.com/news/YR09.06.25_Media_Bio_Fuels.pdf

Although not commercial digester biogas, landfill gas is also being liquefied as fuel at the Altamont Landfill near Livermore, California http://www.wm.com/documents/pdfs-for-services-section/press-release-wm-receives-epa-recognition-landfill-gas-to-energy.pdf several forms such as biogas, electricity through conversion from biogas, with or without heat capture; and conversion of AD residues to energy by combustion or gasification. Alternatively, AD residues could be composted. The majority of water used and nutrients in the straw could be recycled short distances locally to fields. Resulting alternative energy can be used locally or exported. The California Air Resources Board already provides carbon credits for some modified rice production practices, but the scope for reduction from AD systems is much larger[43]. There may be a market for carbon credits generated. Jobs would be created.

Hypothetical Commercial Facility

The suggestion to use rice straw for biogas using a commercial AD system is hypothetical. Only limited data is available, insufficient to provide the quality of data necessary to support commercial investment. Using experimental data (Zhang and Zhang, 1999) and a generic cost calculator (Rapport, 2011), some broad, general impacts can be demonstrated. Three configurations of electricity production or direct gas use were evaluated (Table 38). It is assumed that 30 percent of all biogas produced would be required to operate the system. The three scenarios, and facility types, are based on all remaining biogas used in 1) gas export (70 percent gas export), 2) half gas export and half power sold off-site (35 percent power sales/35 percent gas export), and 3) all biogas converted to power for off-site sales (70 percent power sales).

Table 38: Description of three biopower configurations.

Alternative Biopower Configurations*	Straw Input Rate	Electrical and Heat Use	Electricity Generated for Export	Gas Export
Facility Type 1	140 ton/day	30% of gas production capacity	0%	70%
Facility Type 2			35%	35%
Facility Type 3			70%	0%

** In all cases 30 % of gas production was utilized to supply the electricity and heat demands for the facility.*

By scaling AD facilities to use 140 tons of rice straw per day a single facility would require 51,100 tons of straw annually from 76,650 acres. This is 23 percent of the potentially available straw in the Butte Sink region, a conservative estimate. Multiples of this size facility would allow more rice straw methane emissions to be avoided. This level of use allows for some combustion of fields for phytosanitary purposes, as noted, and return of straw to soils for soil organic matter maintenance. In addition, most nutrients, water and some lignified residues are conserved in AD processes and these can be returned to fields supplying straw. Estimates for capital costs are found in

Table 39. It is difficult to assign commercial values for a hypothetical commercial facility, but using sources developed by Rapport (2011), such a 140 ton/day facility would cost nearly $21

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[43] http://www.arb.ca.gov/cc/capandtrade/offsets/offsets.htm

million to construct and about $1.4 million to maintain annually. Competition among commercial suppliers of AD systems may be expected to help reduce such costs over time.

Table 39: Estimated capital costs for 140 ton/day AD facility construction.

Cost Type		**Facility Type 1 (Million $)**	**Facility Type 2 (Million $)**	**Facility Type 3 (Million $)**
Capital Investment	Facility- buildings and compost	$ 3.000	$ 3.000	$ 3.000
	Digester	$ 15.000	$ 15.200	$ 15.200
	Generator Set	$ 0.640	$ 1.500	$ 1.500
	Gas Cleaning	$ 2.200	$ 1.200	$ 1.200
	Total	$ 20.840	$ 20.900	$ 20.900
Operation and Maintenance	Digester	$ 1.250	$ 1.600	$ 1.600
	Generator Set	$ 0.060	$ 0.130	$ 0.130
	Gas Cleaning	$ 0.110	$ 0.060	$ 0.060
	Composting	$ 0.008	$ 0.008	$ 0.008
	Annual Cost	$ 1.428	$ 1.793	$ 1.798

Essentially all three facilities are equivalent in design but alternatives 2 and 3 require larger or additional generator capacity to meet electricity production demands (based on model used in Rapport, et al.,2011).

Capital Budgeting of Facility Costs

The annual cost of capital can be estimated easily by assigning some values for interest (0.08), and a 10 year payback period. Rounding to $20 million dollars simplifies the math. The annual operation and maintenance (O & M) costs for Facility Type 1 (all natural gas) is estimated to be 6.85 percent of the $21 million in capital costs. More established technologies and facilities will require less O & M. More experimental technologies and facilities will have a higher O & M. A range of O&M costs as a percent of capital are presented in Table 40. Assuming a 7 percent O & M cost on a $20 million investment of this nature is reasonable (shaded in Table 40).

Table 40: Range of annual operation and maintenance (O&M) cost for a $20 million investment.

Percent of Capital	Annual O&M
4.0%	$ 800,000
5.0%	$ 1,000,000
6.0%	$ 1,200,000
7.0%	$ 1,400,000
8.0%	$ 1,600,000
9.0%	$ 1,800,000
10.0%	$ 2,000,000

The estimated total of straw required for each 140 ton/day facility is 51,100 tons/year. We use 50,000 tons of rice straw silage for purposes of estimation. There are many ways to price rice straw removal. It requires labor, and equipment. A reasonable estimate for straw removal in 2011-12 is $20 per ton. It costs the producers to remove the rice straw. It costs more to remove the rice straw and deliver it somewhere off site than it costs to incorporate the straw or to burn it. Using $20/ton as a value is a cost to the rice farmer. This is not a price that generates revenue. A cost-offsetting price of rice straw, or in this case, rice straw silage of $20/ton x 50,000 tons per year results in a feedstock cost to the facility of $1 million dollars, or $500,000/year for every $10 increment in the price of rice straw silage. Other straw crops are not produced at the cost of production but with the anticipation of a return higher than the costs. Therefore in the reference-case here, a commonly used biomass price of $50 per ton is used for illustration.

These fundament annual costs can be combined in different ways to establish a reference for the most most significant costs involved in operating a rice straw silage digester (

Table 41). The first column establishes a target capital cost in dollars. The second column provides the annualized cost of that capital based on 8 percent interest and a 10-year payback period. The subsequent column headings identify variable costs for differently priced feedstocks. The values listed in the 'Annual Cost' row are the annual feedstock costs for 50,000 tons of rice straw silage plus the $1.4 million in O&M costs. The balance of the table then is the combination of the annual variable costs in the Annual Cost row with the annualized cost of capital in the Annual Cost column. The reference-case scenario can be set at $20 million, $1.4 million in O&M, and a feedstock cost of $50/ton. Such a facility would have annual costs of $6.9 million. For a facility to breakeven would require revenues equal to the costs. To operate profitably would require revenues of significantly more than $6.9 million/year based on these assumptions.

Table 41: Annual variable O&M, and feedstock costs with annual capital cost budgeting for 140 ton/day facility.

Rice Straw Digesters		Fuel Costs				
Annual costs		$20/ton	$40/ton	$50/ton	$60/ton	$80/ton
Capital costs	Annual Costs	**$ 2,422,000**	**$ 3,444,000**	**$ 3,955,000**	**$ 4,466,000**	**$ 5,488,000**
$ 10,000,000	$ 1,456,000	$ 3,878,000	$ 4,900,000	$ 5,411,000	$ 5,922,000	$ 6,944,000
$ 15,000,000	$ 2,183,897	$ 4,605,897	$ 5,627,897	$ 6,138,897	$ 6,649,897	$ 7,671,897
$ 20,000,000	$ 2,911,862	$ 5,333,862	$ 6,355,862	$ 6,866,862	$ 7,377,862	$ 8,399,862
$ 25,000,000	$ 3,639,828	$ 6,061,828	$ 7,083,828	$ 7,594,828	$ 8,105,828	$ 9,127,828

The values in

Table 41 are based on specific assumptions, which when varied produce different results. Table 42 and Table 43 vary reference case by the interest rate and payback period in years, respectively. The annual costs of these facilities across these ranges vary from $4 million to $10 million. The lowest cost conditions are in bold and higher costs are shaded in gray. A breakeven annual capital cost of $4 million is used in the following discussion on revenues.

Table 42: Range of annual capital and variable costs across a range of interest rates.

Payback	10 years	$20/ton	$40/ton	$50/ton	$60/ton	$80/ton
Capital Cost	$20,000,000					
Interest Rates	Annual Costs	$ 2,422,000	$ 3,444,000	$ 3,955,000	$ 4,466,000	$ 5,488,000
2%	$ 2,208,000	$ 4,630,000	$ 5,652,000	$ 6,163,000	$ 6,674,000	$ 7,696,000
4%	$ 2,430,000	$ 4,852,000	$ 5,874,000	$ 6,385,000	$ 6,896,000	$ 7,918,000
6%	2664000	$ 5,086,000	$ 6,108,000	$ 6,619,000	$ 7,130,000	$ 8,152,000
8%	2912000	$ 5,334,000	$ 6,356,000	$ 6,867,000	$ 7,378,000	$ 8,400,000
10%	$ 3,172,000	$ 5,594,000	$ 6,616,000	$ 7,127,000	$ 7,638,000	$ 8,660,000

Table 43: Range of annual capital and variable costs across a range of payback period years.

Capital Cost	$20,000,000	$20/ton	$40/ton	$50/ton	$60/ton	$80/ton
Interest Rate	8%					
Payback Years	Annual Costs	$ 2,422,000	$ 3,444,000	$ 3,955,000	$ 4,466,000	$ 5,488,000
5	$ 4,866,000	$ 7,288,000	$ 8,310,000	$ 8,821,000	$ 9,332,000	$ 10,354,000
7	$ 3,741,000	$ 6,163,000	$ 7,185,000	$ 7,696,000	$ 8,207,000	$ 9,229,000
10	$ 2,912,000	$ 5,334,000	$ 6,356,000	$ 6,867,000	$ 7,378,000	$ 8,400,000
15	$ 2,294,000	$ 4,716,000	$ 5,738,000	$ 6,249,000	$ 6,760,000	$ 7,782,000
20	$ 2,007,000	$ 4,427,000	$ 5,451,000	$ 5,962,000	$ 6,473,000	$ 7,495,000

Rice Straw Digestion Facility Revenue Benefits

The revenue side of the 140 ton/day rice straw digester is similarly challenging. There are several assumptions that need to be stated first. Based on the technical information provided by Zhang and Zhang (1999), a rice straw digestion facility of this size could produce 21,500 MWh of power, based on 30 percent power conversion efficiency. Since 30 percent of the biogas produced is required for parasitic load, only 70 percent of the biogas is available for power production. This reduces total power produced to 15,000 MWh.

The fiber and nutrients in the rice straw have some value. It could be composted, or it could be used as fuel in a subsequent thermal conversion process, or used as bedding for dairy cows, or returned as is to fields. The value assigned in this calculation is $10 per ton. For any of these markets moisture content varies as does the volume of fiber. It is also assumed that 1 ton of digested rice straw leaving the digester is approximately the same volume as the rice straw silage entering the digester.

Similarly, it is estimated from the biogas production of the digester that the annual methane content heating value is 244,000 MMbtu. 70 percent of the biogas not consumed by the digester and conversion technologies is available, or 171,000 MMBtu.

Table 44 and Table 45 show the total power revenue and heating value of the methane content of the biogas, respectively. The prices for power and heat value span a wide range and are much greater in the high end prices in which the combined energy and compost revenues begin to align with the $4 million capital cost examples above. These are presented because such high prices have been used in discussions of what green energy could cost. The higher rates for power are similar to those paid in Germany that have resulted in the construction in recent years of more than 8,500 small anaerobic digestion facilities, many of them on farms. These are much higher prices than current rates in California.

Table 44: Power and composting revenue for a hypothetical 140 ton/day rice straw digester facility.

$/kWh	Power Revenue	Compost Revenue	Combined Revenue
$ 0.04	$ 600,732	$ 500,000	$1,100,732
$ 0.06	$ 901,098	$ 500,000	$1,401,098
$ 0.08	$ 1,201,464	$ 500,000	$1,701,464
$ 0.10	$ 1,501,831	$ 500,000	$2,001,831
$ 0.12	$ 1,802,197	$ 500,000	$2,302,197
$ 0.14	$ 2,102,563	$ 500,000	$2,602,563
$ 0.16	$ 2,402,929	$ 500,000	$2,902,929
$ 0.18	$ 2,703,295	$ 500,000	$3,203,295
$ 0.20	$ 3,003,661	$ 500,000	$3,503,661
$ 0.22	$ 3,304,027	$ 500,000	$3,804,027
$ 0.24	$ 3,604,393	$ 500,000	$4,104,393
$ 0.26	$ 3,904,759	$ 500,000	$4,404,759

Table 45: Natural gas equivalent and compost revenue for a hypothetical 140 ton/day rice straw AD facility.

$MMBTU	Biogas Revenue	Compost Revenue	Combined Revenue
$ 4.00	$ 683,826	$500,000	$ 1,183,826
$ 6.00	$ 1,025,738	$500,000	$ 1,525,738
$ 8.00	$ 1,367,651	$500,000	$ 1,867,651
$ 10.00	$ 1,709,564	$500,000	$ 2,209,564
$ 12.00	$ 2,051,477	$500,000	$ 2,551,477
$ 14.00	$ 2,393,389	$500,000	$ 2,893,389
$ 16.00	$ 2,735,302	$500,000	$ 3,235,302
$ 18.00	$ 3,077,215	$500,000	$ 3,577,215
$ 20.00	$ 3,419,128	$500,000	$ 3,919,128
$ 22.00	$ 3,761,040	$500,000	$ 4,261,040

Rice Straw Digestion Facility GHG Emission Avoidance Benefits

Methane that is captured by digesting rice straw in an AD facility reduces uncontrolled emissions to the atmosphere, and its use for power substitutes for the use of fossil natural gas for electricity production or other uses (Table 46). These GHG offset values are based upon a hypothetical example of real BMZ resource levels. But both the yield of energy products and the GHG emission offset estimates are modeled rather than measured. The values in Table 46are presented for illustrative purposes. The calculations are based on a number of critical assumptions. These include the use of Zhang and Zhang (1999) laboratory conversion factors of rice straw to methane in an experimental digester. The methane yield, scaled up to cubic meters of methane per metric ton of rice straw is 172.6 m^3/Mg. This experimental methane yield was reduced by 75 percent to adjust for commercial conditions that would potentially have a shorter residence time in the digester than the experimental values (reducing the digester residence time allows for a smaller digester and also lowers the yield). The natural gas and power estimates are based on the 1.5 ton/acre rice straw yield (Williams, et al, 2008).

The power generation assumptions include a conversion efficiency of 30 percent and a California electricity emissions factor of 124.06 g CO_2 e/MJ or 446.7 g CO_2/kWh (CARB, 2009). The natural gas emissions factor is based on an EPA (2012) value of 0.0053 Mg CO_2/therm. The table is organized by economic facility scenario as well as BMZ rice straw utilization rates of 100%, 66%, 50%, and 33%. The total CO_2 production in the field is based on the CEC (2002) rice straw emission value of 12.2 g CH_4 m^{-2}. The CH_4 Emissions Avoided estimates reflect 50 percent removal of rice straw (technically available at the 1.5 ton/acre yield with 50 percent remaining behind) plus the emission offsets created through natural gas offsets, power offsets, or both. Based on the values presented in Table 46, the rice straw AD, natural gas emissions avoided are 60 percent of the estimated field emissions while the emissions avoided from only electricity production are 57 percent of estimated field emissions. The scenario that produces both natural gas and power is at 58.5 percent of the field emissions.

Table 46: Potential CO_2 equivalents offset by AD of rice straw at a 140 ton/day facility.

Percent of BMZ straw	Mg CO_2 (field)	CH_4 Offsets from Natural Gas Generation (Mg CO_2)		CH_4 Offsets from Power Generation (MG CO_2)		CH_4 Emissions Avoided (Mg CO_2)
		35%	70%	35%	70%	
Power	**Facility 1, Biogas distribution=70% NG:0%**					
100%	92,500		9,061			55,311
66%	60,000		5,980			35,980
50%	47,500		4,530			28,280
33%	30,000		2,990			17,990
Power	**Facility 2, Biogas distribution=35% NG:35%**					
100%	92,500	4,530		3,354		54,135
66%	60,000	2,990		2,214		35,204
50%	47,500	2,265		1,677		27,692
33%	30,000	1,495		1,107		17,602
Power	**Facility 3, Biogas distribution=0% NG:70%**					
100%	92,500				6,709	52,959
66%	60,000				4,428	34,428
50%	47,500				3,354	27,104
33%	30,000				2,214	17,214

These estimates suggest that digesting rice straw silage in a commercial anaerobic digester could reduce rice straw methane emissions by 57% to 60%. This estimate only considers 50 percent of the technically available rice straw removed plus the offset for either power or natural gas avoided from fossil-based sources. It does not include GHG emissions occurring from feedstock harvest, ensiling, and transportation operations to the physical site location. Methane is a more potent GHG factor, however, than CO_2 emissions from other types of operations[44], but no market has yet developed for these credits. Three percent of estimated statewide methane emissions come from rice cultivation[45]. A protocol developed by the California Climate Action Reserve allows for the creation of carbon credits.[46]

Evaluating the Benefits

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[44] http://www.arb.ca.gov/cc/capandtrade/meetings/022015/workshop_presentation.pdf

[45] http://arb.ca.gov/cc/shortlived/slcp_booklet.pdf

[46] http://www.climateactionreserve.org/how/protocols/rice-cultivation/ ; http://www.climateactionreserve.org/wp-content/uploads/2011/12/Rice_Cultivation_Project_Protocol_V1.1_Package_012114.pdf

These estimates provide some benchmarks for policy and planning. Reducing methane emissions from rice straw emissions is feasible, but complex economically. For instance, if a $20 million facility was constructed to achieve, initially, a 60 percent reduction of methane emissions, a grant for 50 percent of capital costs would reduce these to $10 million. A low interest loan could reduce the interest to 2 percent, and a 50 percent feedstock purchase subsidy, such as those provided by the federal BCAP program, could provide a $40 per ton rice straw silage price delivered for $20 to the facility. Extending the payback period from 10 years to 20 years would further lower the annual cost of capital. However, there are many assumptions in this illustration. Changing them alters the costs. The annual cost of capital, O&M (even maintaining the $1.4 million annual fee), and using the $20/ton price, reduces the annual costs to $3 million. This would lower the 'green' energy costs of such a facility to $0.17/kWh for power and $17/MMBtu for natural gas.

Additional cost savings could be found in combining (co-digesting) materials with a higher energy value than rice straw silage like food processing residues, the organic fraction of MSW collected locally, or glycerin from a biodiesel facility in the same digester. Perhaps there may be a way to combine rice straw silage digestion at a public wastewater treatment facility which would lower the cost of the digester portion of the capital costs. Using the residual solids in an onsite thermal conversion facility could likely increase the value of the digested solids to a value greater than $10/ton for solids. This example facility illustrates how multiple excess biomass liabilities could be combined to achieve multiple economic and environmental benefits.

Economic details remain to be determined. However on the basis of available feedstocks, conversion to power, and methane emissions avoided, the rice straw silage anaerobic digester facility has benefits. Table 47 illustrates these for a typical AD facility. The first two rows of the table show the inputs, energy output, and methane emissions avoided for a hypothetical, 140 ton/day rice straw silage facility. In this table the energy output is presented as either power (MW) or heat (MMBTU). The lower two rows scale up the 140 ton/day facility and scale this technology up to the total rice acres in the Butte Sink region, or 4.5 AD units. If this CH_4 were compressed and used for CNG, 1.54. MMgge and 6.85 MMgge could be created respectively.

Table 47: Estimated benefits from anaerobic digestion of rice straw.

		Feedstock BDT	Power Capacity MW	Heat Value MMBTU	CH_4 Avoided Mg CH_4
1, Rice straw AD unit	Power Production	50,000	1.9		55,000
140 tons/day	Heat production	5,000		177,000	53,000
All BMZ rice straw	Power Production	223,000	8.5		245,000
4.5 AD units	Heat production	223,000		788,000	236,000

Barriers

The Cost of feedstocks

California is a high cost state for crop production due to the need for irrigation, competition among high valued crops, and the higher cost of land and regulatory costs. But the potential for energy feedstock crops including oilseeds has been estimated here. It is less certain that if produced, the price of crop feedstocks will be low enough to allow profitable conversion to fuels. In part, this is difficult to predict. Table 35 has estimated costs per gallon for crop feedstocks based on 2012 prices, the most recent year for which appropriate prices could be derived. The feedstock cost for canola is estimated as $2.82 per gal, compared to a lower feedstock cost of $1.50 to $1.80 per gallon based on current prices for FOG (May 2015). This higher price is a barrier to its use for industrial (fuel) purposes. To reduce the cost of canola feedstock grown in California, higher yields and lower production costs are necessary. Higher yields than those assumed in this analysis seem likely if improved varieties are used (George et al., 2015; Kaffka et al 2013). A yield of 3500 lb acre would allow growers to profitably sell canola seed with an oil value less than $2.00 per gal, closer to the higher proceed for FOG-derived biodiesel. Lower costs may be possible as reduced tillage systems improve in California, eliminating most production steps apart from planting, fertilization, weed control and harvest. There is an active reduced tillage research program in California and slow adoption of these techniques (Mitchell et al., 2012). They are particularly suited to crops like canola and wheat, grown in winter with little to no irrigation, especially in rotation, but more applied research with both crops is needed to reach a wider scale of adoption. Farming practices which save money also reduce energy costs and the carbon intensity of feedstock production.

Conservation tillage allows growers to plant directly into fields that contain residue from prior crops. ***Above*, tomatoes are transplanted into cover crop residues (triticale, rye and pea) in Five Points.**

Mitchell et al., 2012.

Among the other alternative feedstock crops evaluated, energy cane has the lowest feedstock cost per gge (Table 35), making it the most likely feedstock source on the basis of price alone. Others will only be sued if feedstock price can be reduced, and the need for low carbon intensity fuels in California creates demand for alternatives at higher prices.

ILUC

There are no ILUC value(s) provided here for in-state fuel producers, but our analysis suggests that, rationally, these would be close to zero. Except for the Imperial Valley, crop substitution is small relative to available land, may use fallow land or idle periods in production systems in some instances (Camelina, some canola, some beets), and may displace some (minor) crops which are not accounted in the models used for ILUC analysis. The scale of displacement is not detectable in global markets, so there could be no price signal to stimulate land change elsewhere. But if indirect effects are still considered to be essential for regulatory purposes, they are at least as likely to be positive as negative. For example, in the case of some oilseed feedstock production that could develop based on production from vineyards and orchards as winter cover crops, ILUC values would be zero or perhaps negative if it could be argued that producing oilseeds in these settings spares land in places like Indonesia where large terrestrial carbon losses occur (Perrson et al, 2014). Babcock and Iqbal (2014) have recently argued that the methods used by CARB for ILUC significantly overestimate ILUC values. If true, then ILUC values for in-state feedstocks will have very low values, essentially being a case with very low risk of indirect land use change effects (Faaj et al.,). It is also plausible, as asserted by Persson et al., (2014) that biofuel production within the US on land already used for agriculture is likely to reduce GHG emissions when substituted for fuels produced in regions where land use change may be associated with feedstock production. These would be places like Brazil, Indonesia and Argentina. To the degree that in-state production of fuel ethanol and biodiesel replace production from other locations. Land use change may be spared, not created.

Whether the state's approach to ILUC assessment (modeling) can accommodate the actual effects of the small scale, largely undetectable influences from crop substitution suggested by this analysis, either in terms of methods or regulatory process, remains to be seen. But accurate assessment is crucially important if the LCFS is to serve the interests of the public and operate with some claim to correspondence with factual effects. It is also the case that for in-state biofuel production to occur, low or negative ILUC values are necessary to allow these fuels to meet the needs for low carbon intensity fuels in forthcoming years.

Also uncertain is how the state might regard in-state industrial crop production that competes with artificial markets like those operating in China. For example, land and other resources applied to biofuel feedstock production would result in much greater economic benefits to the state and its rural residents in disadvantaged communities than those resulting from exporting low value forages to China, for example. It is not clear how a climate policy justified as being in the long-term public interest, focused on the well-being of the state's citizens can justify discriminating against in-state business development through a mechanism used for GHG calculations that may favor arbitrary markets for other agricultural products, when these may be subject to political control over their size and terms of trade (Figure 5a and b).

Policy certainty

The cost of building new, complex biorefineries is very large, and results in a high per gallon capital cost. To encourage production of fuels using new technology and facilities, policy stability is needed to sustain demand for fuels from new types of processes during their early years of operation and operational improvement. Both the Federal RFS2 and LCFS stimulate and maintain demand for low CI fuels, and provide credits (RINS and carbon credits) that have economic value for alternative fuel producers. The RFS2 has become an annually determined volumetric requirement. In recent years, the volume required has only been determined during the year when it applies or even appeared after the actual accounting year had begun. The volumes mandated under the RFS2 for different advanced and cellulosic fuels have become an object in a political contest and rules by EPA have been delayed far beyond legislated deadlines[47]. This makes the policy an unreliable basis for significant capital investments[48].

The state of California has been more consistent in its application of the LCFS but has been subject to legal challenge focused on its authority to set rules and conditions for other parties outside of the state. Some of these legal challenges have not been resolved. In its own way this creates a different kind of uncertainty, and acts as a barrier to innovation and new investment.

Advancements in science

Land use, economic thresholds, and employment and other economic effects for agricultural biofuel production in California have been estimated more accurately here than in any other previous assessment by combining new data and methods to assess land use and cropping patterns, account for such patterns in economic models, and reflect the broader economic outcomes of new bioenergy enterprises in the state. We believe these values represent a realistic potential for in-state biofuel production from crops in California. Crop substitution is estimated on a regionally realistic basis and provides far better estimates than those possible using much more large-scale and largely irrelevant models for California. Additional assessments for wildlife, erosion and other agroecological consequences of biofuel feedstock crop production in California are reported elsewhere (Kaffka et al. 2015) in an earlier integrated assessment but reinforce the modest consequences of crop shifting discussed here. This analysis provides some assurance that undesireable secondary effects from new biorefneries are unlikely. There has been no equivalent integrated assessment of these effects apart from this and two earlier analyses fusing he same modeling tools, but less current data. Additional estimates of biogas production potential of the state’s two largest residual agricultural biomass sources are also provided. Biogas can be conditioned and used as CNG (Ong et al., 2015), but the ultimate amount available for this purpose depends on state policies supporting anaerobic gestion, GHG

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[47] http://www.biofuelsdigest.com/bdigest/2014/11/21/epa-abandons-rfs-rulemaking-for-2014/

[48] http://www.eenews.net/greenwire/2014/11/21/stories/1060009424

emissions, and alternative uses for biogas apart from transportation fuel. Only initial estimates for fuel or power from these sources are provided here. There is much current work occurring, especially with respect to dairy manures that will improve on this initail estimate. Costs for producing fuels fromthese resources currently arehigh, but with time could be reduced. Nonetheless, the potential for biofuels/biopwere from both sectors provides opportunities for expansion of in-state alternative transportation fuel production.

Measurement of success in achieving goals/objectives

All goals identified in the SOW have been addressed. Additional materials on agricultural residuals and their biofuel potential have been added in review at the request of CEC staff.

Insights/observations/implications/conclusions

Insights/observations/implications/conclusions

The most important state policies with respect to transportation fuels are the LCFS and the Alternative and Renewable Fuel and Vehicle Technology Policy (ARFVTP-AB118) program, which provides grants and loans to new companies and groups to help develop lower GHG emission alternative fuels and power to current transportation systems in California. It supports innovation in alternative transportation fuels and infrastructure through modest investments through grants and loans to promising new in-state businesses dedicated to meeting the state's future alternative transportation needs. Federal policies like the Renewable Fuel Standard (USEPA, 2009) also provide incentives for the development of new businesses focused on alternative sources of fuels and power. This evaluation focuses on the most promising biofuel alternatives derived from new feedstock soruces dereived from agricultural crops and forest residues in California. It provides independent guidance to the the AB 118 advisory committee and the Commission's directors about both quantitative estimates for fuels and the costs and economic benefits of new biofuel businesses. A related report (Kaffka et al., 2014) also provides an earlier set of estimates based on 2007 prices, but also detailed discussion of environmental effects, the concept of sustainability, certification, how in-state production compares with such general standards, and unique aspects of the LCFS with respect to sustainability.

This analysis suggests that several small, biomass-based businesses could develop in California in different locations in the state, using locally optimum crop resources, equivalent to approximately 200 MMgge per year under favorable conditions. These biomass resources vary by type and location in the state. Based on estimated or self-reported fuel CI values, these firms can competitively provide fuels and associated power, compared to other available or foreseeable biofuel sources, including some provided by competing producers in Brazil and elsewhere. In-state fuel production will be supported on existing agricultural land, within the level of natural resources like water traditionally available to farmers, with no significant impact on wildlife, soil erosion or soil quality compared to incumbent crop production systems. In many cases, new crop enterprises for bioenergy use underutilized resources (winter fallow periods, slack periods in cropping systems) or otherwise complement existing cropping systems economically. If the effects of the current drought on state water supplies and related public policies prove to be permanent, new analyses would be required. If less water is available, some of the potential biofuel businesses currently foreseen as viable would not be able to develop.

Because the number of biofuel businesses and related amount of land anticipated is small relative to total land use for farming in California, we estimate no significant market mediated effects on land use elsewhere in the world due to the development of one or more these small-scale enterprises and the minor crop nature of the feedstocks, which for the most part lie outside of the scope of existing global economic models used to predict such effects. In-state production can be seen as reducing or conserving any equivalent adverse effects of otherwise imported fuels on land use in the locations from which they would be imported. ILUC carbon alues should be close to zero. The ultimate assessment of such effects, however, lies with the Air Resources Board and policy decisions about how to calculate such small-scale impacts. These are new analytical issues since new businesses are only beginning to be proposed in California, but the analyses provided here include reasonable accounts for potential, location specific crop substitution patterns otherwise unavailable from other models. These provide the best available basis for judging such market related effects from in-state feedstock production.

The beneficial social and economic consequences of creating new biorefineries in California are large, especially in rural areas where many disadvantaged groups live. The creation of these biorefineries would be an effective way for the purported economic benefits of the state's GHG reduction policies to be distributed to disadvantaged, rural populations and regions. For the most part, novel biomass transformation technologies are not needed to allow new entry level biofuel businesses to operate in California. The barriers are primarily financial and vary on a case by case basis. The analyses provided here suggest that the development of new biorefineries for in-state biofuel production should be supported by the ARFVTP program when companies can provide a plausible business model. There are few risks of adverse landscape outcomes and new fuels must have low CI values to be viable. There is significant potential for social and economic well-being in rural areas, making new projects desirable.

Estimates of residual based fuels from dairy manure and rice were also added in the review stage to this report for the sake of comparison with new crop feedstock based biofuels. Dairy manure estimates are very preliminary, because the state's policies affecting this sector, especially manure management and short lived climate pollutant reduction (CH_4), are in a state of flux and work is in progress. We estimated that if half of the manure available from milking cows and dry stock on the state's dairy farms were converted to methane, then 158 MMgge of CNG could be produced, a potentially large amount. But this is an optimistic estimate. Other estimates are possible depending on still developing state incentives and regulatory developments, so this estimate is not definitive. A more exact potential amount and cost for this CNG fuel cannot be accurately estimated until further policy development occurs, related to both GHG emissions form dairies and water quality protection. For rice, an Anaerobic Digester fermenting straw from land near a local rice drier in the Butte Sink region could generate approximately 1.55 MMGgge of CNG, while 4 such AD systems in the same location would generate approximately 6.2 MM gge. All alterantive fuel source (new sources and resdiuals) add up to 350 to 400 MM gge of alternative fuels, if all these diverse pathways were to be developed. All prudent agricultural and feedstock sources and pathways should be developed.

Further research

Some of the research needed to support the development of prudent crop-based bioenergy enterprises is traditional agronomic research, focused on yield increases and production cost reductions. Such research is needed but not necessarily the function the California Energy Commission to support.

The GHG consequences of cropping practices have to be accounted if feedstocks are to be suitable for the production of low carbon intensity fuels. The same economic model (BCAM) that is used to identify new bioenergy feedstock production opportunities in California can also be used to more fully and specifically evaluate the GHG consequences of crop shifting in the state forindividual biofuel businesses. Additional research and model development could expand the capacity of the BCAM model to simultaneously account for the ALCA based GHG effects of crop shifting. Each crop choice implicitly includes an associated carbon budget, which if made explicit through additional LCA analyses, could more fully quantify judgements about the GHG consequences of shifts in complex crop rotations. This work should be supported.

The need for on-going analysis in a dynamic area of economic activity like agriculture is constant. Agriculture is dynamic, with farmers adjusting constantly to new resource constraints, regulations and economic opportunities based on prices and markets. As a result, land use choices change yearly in conformity with new developments and farmers' diverse responses to them. So data analysis about farmers' potential choices remains an ongoing requirement**.** For example, the severity of the current drought has resulted in extensive fallowing of farmland and a shift to more high valued perennial crops. These changes were the result of other changes in relative prices among annual and perennial crops in recent years, exaggerated by the drought. The BCAM model can be used in an ongoing manner to assess new developments in both policy and the economics of farming. Additional research on the effects of new constraints related to developing public policies in California like limits on the use of nitrogen fertilizer, or permanent reductions in water supplies, also can be modeled for both economic and GHG consequences. This type of information would allow the California Energy Commission to evaluate the consequences of new projects seeking funding under the ARFVTP involving the use of agricultural land for bioenergy purposes, relative to the state's larger GHG reduction objectives. The Commission could support on-going efforts in this regard and results could be made public through the CEC website and CBC websites.

The use of residual MSW biomass resources for fuel or power production appears beneficial from the GHG reduction perspective[49], suggesting that other residual products will similarly

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[49] http://www.arb.ca.gov/fuels/lcfs/2a2b/internal/hsad-rng-rpt-062812.pdf; http://www.arb.ca.gov/fuels/lcfs/2a2b/2a-2b-apps.htm

produce very low CI fuels. Additional research in this area is warrented. Biorefinieries using both purpose grown feedstocks and residual feedstocks have not been developed yet in California or in other locations to any significant extent. The LCA value used here for the energy beet scenario is based on a biorefinery that uses nut tree residiues for power, and converts some of its own internal residuals to biogas. So it provides one potential example of an integrated biorefinery (Alexiades, 2014). Future research focusing on complementary bioenergy processes in biorefineries, using diverse feedstocks, would be beneficial.

Improved estimates for the costs and benefits of residual agricultural biomass (manures, rice straw) use for power or fuel are needed, both to predict more accurately the potential for the development of these uses, and their comprehensive costs and benefits. It would be useful to more fully analyze the potential benefits of using both these resources under current price and policy conditions, and whether using multiple feedstocks makes sense.

Knowing the economic consequences of potential bioenergy businesses may help guide CEC in determining the most beneficial types of investments to make under the AB 118 program. The IMPLAN data base is used for assessing the economic consequences of new businesses in the state. Default values are available for analogous manufacturing facilities but new data have recently become available in 2015 that more accurately reflect current conditions. It would be valuable to use updated IMPLAN data and the most current estimates for biorefinery design. This work could be supported in future research efforts.

Publications

Publications based on these analyses are now in preparation. We anticipate 4 or 5 publications focused on methods and outcomes and the overall issue of biofuel feedstock production in regions with intensive agriculture.

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Appendix A: Data processing and classification of California's Principal Cropping Systems

The goal of this analysis is to discover natural grouping(s) of crops (cropping systems) in California by location. Data extracted from the PUR database is divided into five tables based on the predefined production regions. Non-metric multidimensional scaling (NMDS), an ordination[1] method, was used to project the data sets into fewer dimensions, and a K-means clustering algorithm is used to assign each PUR section to a group. The R package ecodist was used to perform the analysis ((R Core Team 2014, Goslee and Urban 2007).

Given a set of data objects with multiple variables associated with them, NMDS presents the dissimilarity between objects based on the variables, while preserving the ordering relationships among objects. The result present objects in a small and specified number of dimensions (Legendre and Legendre 2012). The objects in our analysis are the PUR sections and the variables are the crop cultivation frequency within the ten-year period. A distance matrix based on Manhattan distance was created to be used in the NMDS. 2 to 4 dimensions for the production regions are chosen based on stress, a goodness-of-fit measure, to be used in the K-mean clustering. The stress value can be calculated in several ways, and this formula (Kruskal 1964) was used in the ecodist package.

$$Stress = \sqrt{\sum_{h,i}(d_{hi} - \hat{d}_{hi})^2 / \sum_{h,i} d_{hi}^2}$$

Where d_{hi} is the dissimilarity of the sample objects; $\hat{d}_{hi}$ is the distance predicted from the regression model. Smaller stress value indicates that the ordination better summarized the observed distances.

The k-means algorithm requires a user-specified number of clusters. K was determined by running k-means with multiple different initial partitions and choosing the partition with the smallest squared error.

Yearly average acreage planted values of crops in each cluster were then queried from the PUR database after the cluster analysis. PUR data are based on farmers' reporting, but the spatial scale is different from the reporting scale. Each section may contain one or more fields and the data table has several columns that can be used to filter out duplicated records. The total acreage of each crop/year can be validated with crop acreage data published by county individual agricultural commissioners' offices. The querying algorithm was based on a combination of several variables in the PUR database and eliminating the acre-planted values of crops which occur rarely are in the largest and smallest 1% of the yearly reported records. This equals approximately X acres in the state as a whole. For example, the total harvested acreages of fresh market tomato and processing tomato in Fresno County, 2012, were 106,030 acres (8,430 and 97,600, respectively) (USDA National Agricultural Statistics Service 2014). The total tomato planted acreages queried from the PUR database was 108,024.09 acres.

Figure 34 to Figure 38 present the clustering results of the 5 production regions. The spatial distributions of the clusters indicate the spatial aggregation of similar crop choosing pattern, which can be further analyzed with potential economic and environmental factors. Table 48 to Table 52 shows the cluster and percentage crop selection frequencies in each region.

Sacramento Valley (SAC)

Sections in the SAC region are clustered into 8 groups. Cluster #5 represents the major rice cultivation in California.

Figure 34: Sacramento Valley cropping pattern cluster.

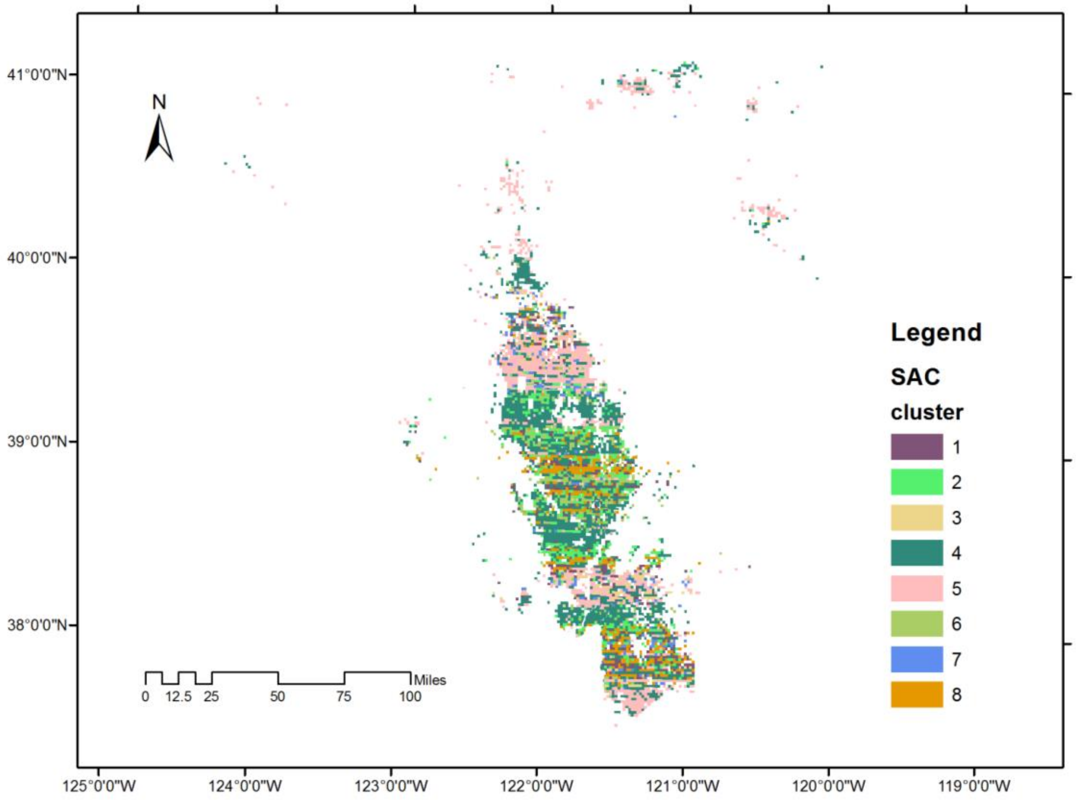

Table 48: Sacramento Valley cropping pattern cluster with frequency of crop selection.

Crop	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5	Cluster 6	Cluster 7	Cluster 8
Alfalfa	4.55%	39.94%	3.61%	18.00%	2.13%	5.89%	26.54%	28.59%
Barley	0.66%	1.00%	0.06%	1.89%	0.24%	2.35%	0.66%	0.23%
Beans	8.14%	2.31%	8.72%	5.04%	0.89%	3.09%	2.60%	3.98%
Bermudagrass	0.01%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%
Broccoli	0.74%	0.03%	0.02%	0.24%	0.01%	0.15%	0.06%	0.28%
Carrot	1.39%	0.28%	1.40%	0.46%	0.06%	0.13%	0.81%	0.63%
Corn	10.65%	16.93%	5.71%	8.84%	2.15%	43.18%	5.87%	10.55%
Cotton	0.87%	0.57%	1.79%	0.35%	0.51%	0.84%	0.66%	0.18%
Foragefodder	0.38%	2.39%	0.04%	3.95%	0.58%	3.39%	1.66%	0.52%
Garlic	0.34%	0.20%	0.00%	0.27%	0.03%	0.11%	0.09%	0.17%
Lettuce	0.14%	0.02%	0.04%	0.09%	0.00%	0.00%	0.00%	0.18%
Melon	7.02%	0.99%	9.44%	3.06%	0.91%	1.83%	3.31%	2.48%
Oat	2.51%	8.16%	0.43%	12.38%	1.08%	14.30%	3.48%	3.13%
Potato	0.20%	0.11%	0.04%	0.39%	0.00%	2.57%	0.11%	0.09%
Rape	0.03%	0.00%	0.00%	0.00%	0.00%	0.00%	0.04%	0.04%
Rice	1.56%	0.66%	31.98%	7.91%	86.40%	0.72%	31.85%	0.29%
Ryegrass	0.52%	2.59%	0.02%	1.83%	0.09%	1.28%	1.19%	0.60%
Safflower	3.13%	2.81%	3.88%	2.25%	0.70%	1.98%	1.56%	3.29%
Sorghum	0.52%	2.16%	0.33%	0.92%	0.15%	1.09%	0.47%	0.77%
Sudangrass	0.13%	1.59%	0.04%	1.12%	0.07%	2.92%	0.17%	0.41%
Sugarbeet	0.00%	0.03%	0.00%	0.04%	0.00%	0.21%	0.00%	0.03%
Tomato	32.71%	3.46%	16.01%	7.45%	0.98%	3.81%	4.46%	24.10%
Wheat	23.79%	13.76%	16.44%	23.55%	3.00%	10.14%	14.40%	19.46%

Northern San Joaquin Valley (NSJ)

Sections in the NSJ region are clustered into 4 groups. Cluster #1, #2, and #3 have 2 to 3 prominent crops that account for about 80% of crop chooses, and cluster #4 is spatially distributive with crops that change constantly over the 10 year period.

Figure 35: Northern San Joaquin Valley cropping pattern clusters.

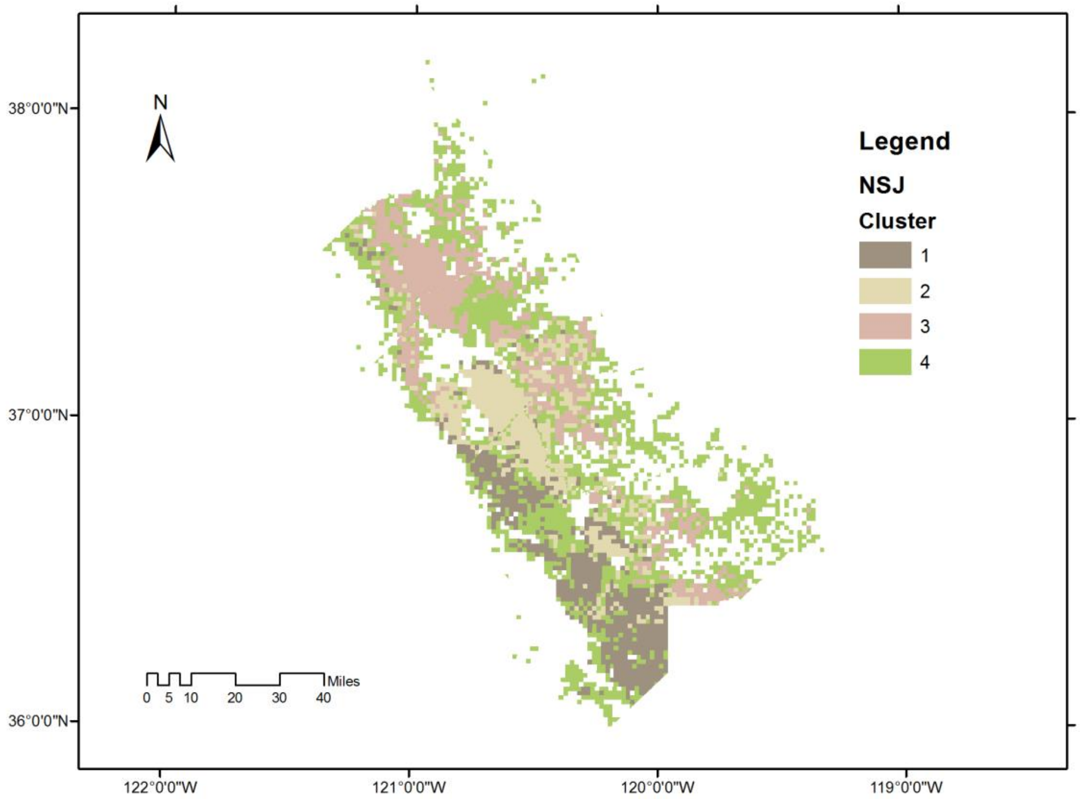

Table 49: Northern San Joaquin Valley cropping pattern clusters with frequency of crop selection.

Crop	Cluster 1	Cluster 2	Cluster 3	Cluster 4
Alfalfa	2.72%	29.49%	25.66%	15.99%
Barley	1.06%	1.33%	0.39%	1.62%
Beans	2.24%	1.15%	3.05%	7.29%
Bermudagrass	0.00%	0.00%	0.00%	0.01%
Broccoli	1.12%	0.20%	0.27%	2.27%
Carrot	0.29%	0.23%	0.04%	0.47%
Corn	2.09%	12.67%	33.26%	14.34%
Cotton	30.31%	25.45%	1.80%	9.63%
Foragefodder	0.05%	0.20%	0.88%	0.64%
Garlic	7.19%	0.20%	0.00%	0.66%
Lettuce	6.49%	0.57%	0.23%	2.36%
Melon	2.43%	1.02%	0.35%	2.37%
Oat	0.32%	3.27%	17.87%	11.91%
Potato	0.00%	0.04%	2.29%	5.55%
Rice	0.33%	0.71%	0.25%	1.46%
Ryegrass	0.00%	0.00%	0.03%	0.06%
Safflower	1.17%	0.17%	0.05%	0.32%
Sorghum	0.07%	0.08%	0.25%	0.27%
Sudangrass	0.03%	0.40%	1.13%	0.51%
Sugarbeet	1.30%	2.24%	0.44%	0.53%
Tomato	29.74%	11.36%	2.49%	10.28%
Wheat	11.03%	9.20%	9.26%	11.47%

Southern San Joaquin Valley (SSJ)

Sections in the SSJ region are clustered into 2 groups. Both clusters are characterized with prominence of field crops. Cluster #1, however, has higher frequency of horticultural crops.

Figure 36: Southern San Joaquin Valley cropping pattern clusters.

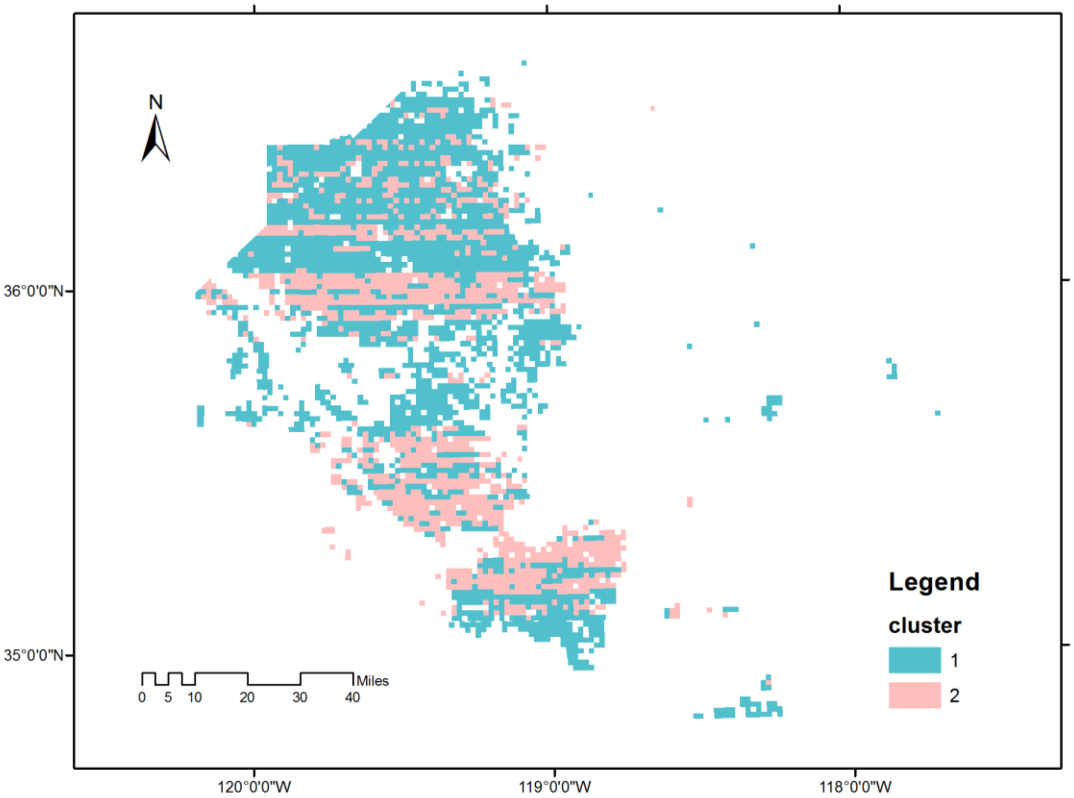

Table 50: Southern San Joaquin Valley cropping pattern clusters with frequency of crop selection.

Crop	Cluster 1	Cluster 2
Alfalfa	14.88%	25.20%
Barley	0.72%	0.38%
Beans	1.67%	1.31%
Bermudagrass	0.02%	0.00%
Broccoli	0.86%	0.49%
Carrot	10.11%	0.84%
Corn	5.45%	26.20%
Cotton	24.75%	15.08%
Foragefodder	0.05%	0.07%
Garlic	2.01%	0.23%
Lettuce	1.30%	0.14%
Melon	1.91%	0.20%
Oat	3.97%	2.61%
Potato	6.46%	0.23%
Rape	0.04%	0.00%
Ryegrass	0.06%	0.07%
Safflower	1.77%	0.17%
Sorghum	0.97%	2.32%
Sudangrass	0.25%	0.28%
Sugarbeet	0.64%	0.66%
Tomato	6.52%	0.64%
Wheat	15.57%	22.87%

Coastal California Valley (COA)

Sections in the COA region are clustered into 2 groups. Cluster #1 is prominently devoted to vegetables, while cluster #2 has more field crops and the crop choice changes more frequently. This cluster includes some rain-fed, alternate fallow systems associated with coastal mountain grazing systems.

Figure 37: Costal California cropping pattern clusters.

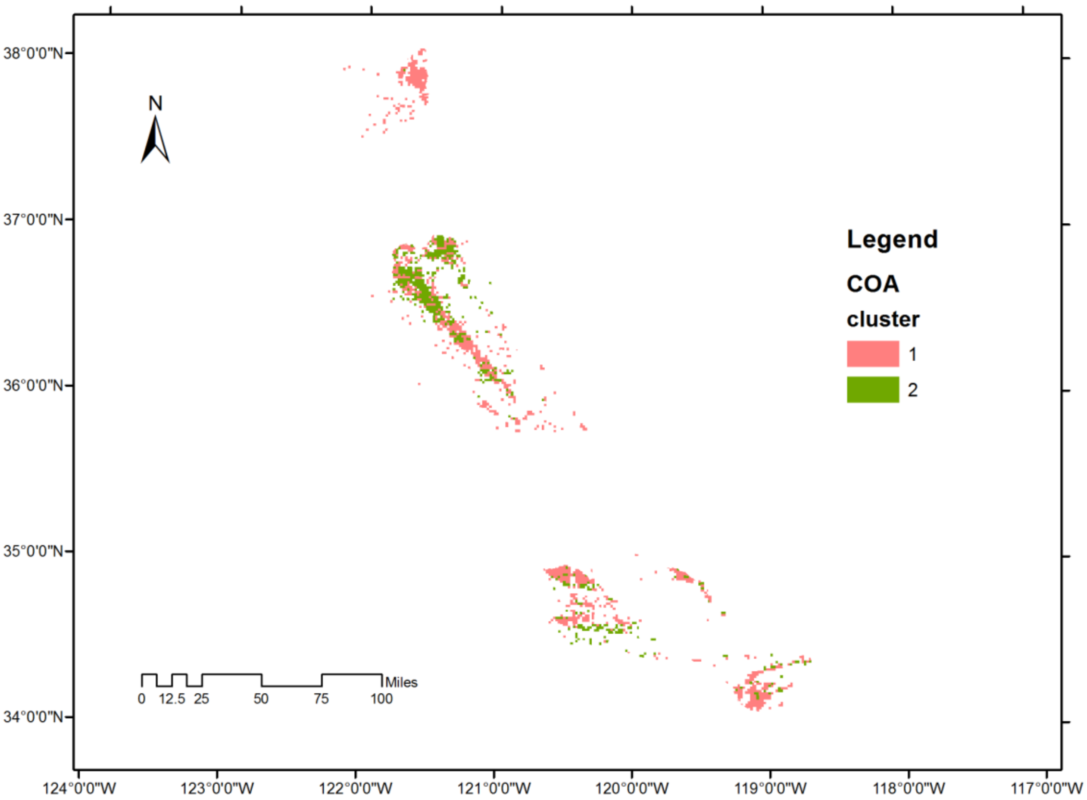

Table 51: Coastal California cropping pattern clusters with frequency of crop selection.

Crop	Cluster 1	Cluster 2
Alfalfa	6.80%	0.61%
Barley	4.60%	0.42%
Beans	7.19%	8.25%
Bermudagrass	0.02%	0.00%
Broccoli	10.63%	34.66%
Carrot	6.75%	5.38%
Corn	9.74%	1.55%
Foragefodder	3.71%	0.07%
Garlic	1.27%	1.63%
Lettuce	19.32%	40.51%
Melon	0.58%	0.30%
Oat	12.67%	1.82%
Potato	1.54%	0.32%
Rape	0.02%	0.01%
Ryegrass	0.27%	0.04%
Safflower	0.22%	0.01%
Sorghum	0.05%	0.02%
Sudangrass	0.15%	0.05%
Sugarbeet	0.22%	0.12%
Tomato	9.39%	3.65%
Wheat	4.86%	0.57%

Southern California Valley (SCA)

Sections in the SCA region are clustered into 3 groups. Cluster #2, the horticultural crop production area, is the smallest among the clusters in SCA.

Figure 38: Southern California cropping pattern clusters.

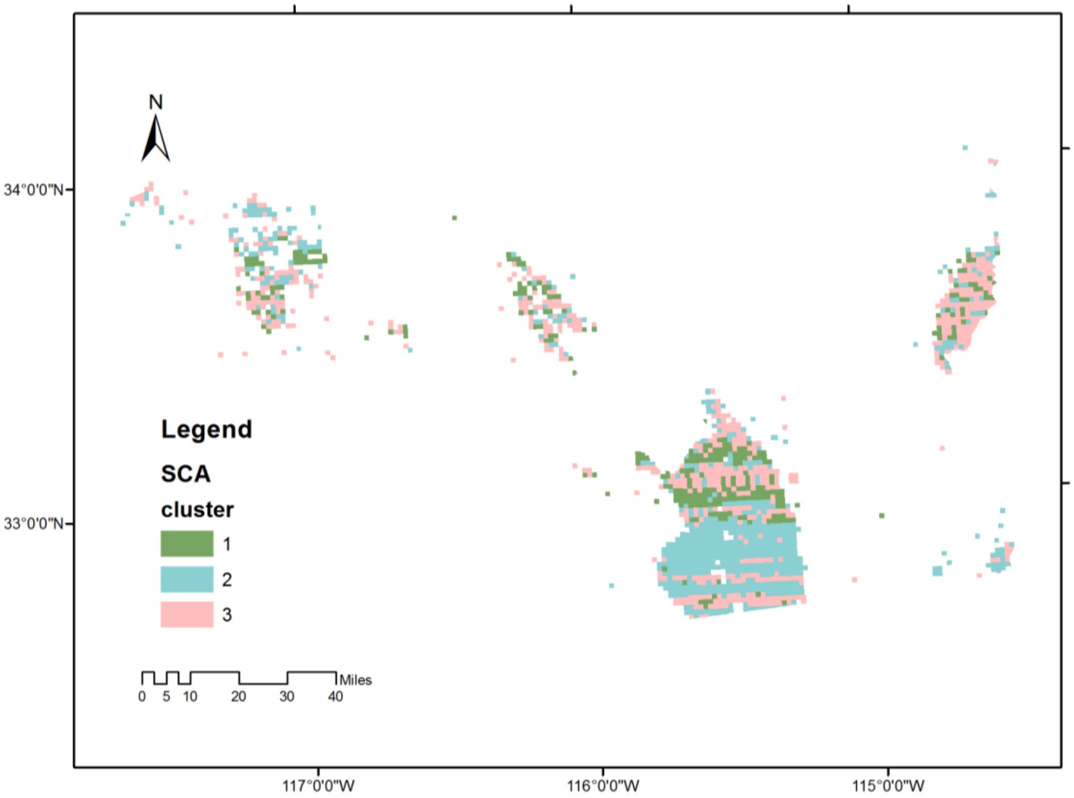

Table 52: Southern California cropping pattern clusters with frequency of crop selection.

Crop	Cluster 1	Cluster 2	Cluster 3
Alfalfa	23.34%	11.17%	37.19%
Barley	0.05%	0.53%	0.06%
Beans	0.13%	3.68%	0.08%
Bermudagrass	1.51%	6.91%	9.29%
Broccoli	9.26%	7.13%	2.84%
Carrot	9.05%	7.15%	1.59%
Corn	5.26%	8.39%	2.27%
Cotton	2.21%	1.52%	7.61%
Foragefodder	0.44%	1.02%	1.82%
Garlic	0.05%	0.02%	0.10%
Lettuce	20.67%	15.08%	2.42%
Melon	3.68%	6.03%	1.90%
Oat	0.24%	2.68%	0.95%
Potato	1.01%	6.05%	0.29%
Rape	0.23%	0.35%	0.63%
Rice	0.00%	0.02%	0.00%
Ryegrass	0.03%	0.41%	0.20%
Safflower	0.01%	0.67%	0.00%
Sorghum	0.05%	0.83%	0.47%
Sudangrass	2.39%	1.36%	1.96%
Sugarbeet	6.35%	2.05%	13.74%
Tomato	0.35%	1.22%	0.15%
Wheat	13.70%	15.73%	14.45%

Appendix B: Crop Budgets

In order to get the most accurate results from running the Bioenergy Crop Adoption Model (BCAM), it is important to use the most realistic data available about input costs, yields, prices, water use, and land used for growing the incumbent crops in the different cropping systems. The difficulty becomes knowing what the best year and best data is, to represent a normal year in California, due to changing factors such as fuel costs, varying crop prices and water availability.

In prior work, BCAM has simulated outcomes using 2007 price level (Kaffka and Jenner, 2011). More recent data is used in the current analysis. Crop production cost information was collected from the information provided by University of California, Davis Cost and Return Studies[50], with the exception of sugarbeets and bermudagrass, which were found in the University of California Agriculture and Natural Resources' Guidelines to Production Costs and Practices (2013). The list of incumbent crops is available in Table 53. Whenever available, analyses created

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[50] coststudies.ucdavis.edu

from 2007 through 2013 were used. However, some crops have not had current cost studies performed. In these cases, the most recent analysis available was used instead.

The prices paid for crop production inputs and for crops sold change constantly. Under such circumstances, it is difficult to identify an average or baseline year. The use of PUR data described above does provide an estimate of longer-term crop choice patterns across California's diverse agricultural landscape. These patterns are based on farmers' deliberations and choices over a longer period of time under the influence of these dynamic economic circumstances. Somehow, economic prices must be chosen as a basis for analysis. Since the crop budgets available were developed over a multi-year period, all input and costs were set subsequently adjusted to 2012 prices. That year was chosen based on judgments about the effects of different levels of drought on prices and land costs (Figure 39), as likely to reflect the most recent year with the least perturbations due to water restrictions. Crops without data from the San Joaquin Valley were edited to change the irrigation costs to reflect water costs in the San Joaquin Valley, which are higher than other areas of the state. For the crops with multiple cost and return studies available, costs were averaged. An example of this is alfalfa, which had multiple studies available for 2012 in the same region. For the crops that did not have data available for 2012, the data from the best most representative year was chosen, and the costs were multiplied by the Consumer Price Index[51] set to 2012 prices. An example of this is wheat, whose costs were based on 2013 data.

The next step was finding the average yield per acre and price received for each crop. This data was found on the USDA's National Agricultural Statistics Service webpage[52], based on 2012 data for the state of California.

Once all crop input prices and costs were set to 2012 price levels, a quick profit check was done to make sure all the crops had a positive profit level based on the information provided. It sometimes occurs that farmers grow crops that turn out to be unprofitable in a given year, due to a variety of reasons. Some crops are complementary, such as broccoli and lettuce. Some crops are grown despite a risk of loss because they have value in crop rotations for weed and pest management purposes, or fill a winter niche that cannot be used for warmer season corps (wheat). Market prices sometimes are not predictable, especially for produce crops. To use BCAM, positive profits, even marginally positive, are needed for all incumbent crops, so prices and yields were adjusted for this purpose where necessary. The crops requiring some adjustment were broccoli, corn, forage fodder, garlic, lettuce, lettuce, melon, oats, potatoes, rice, safflower, sorghum, sugar beets, and tomatoes.

To adjust negative values, yield and price information from the cost and return studies and NASS data over several years were combined. Data from NASS was preferred, but if no NASS data were available or provided only negative returns, averages from ARE cost and return

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[51] data.bls.gov/cgi-bin/cpicalc.pl

[52] quickstats.nass.usda.gov

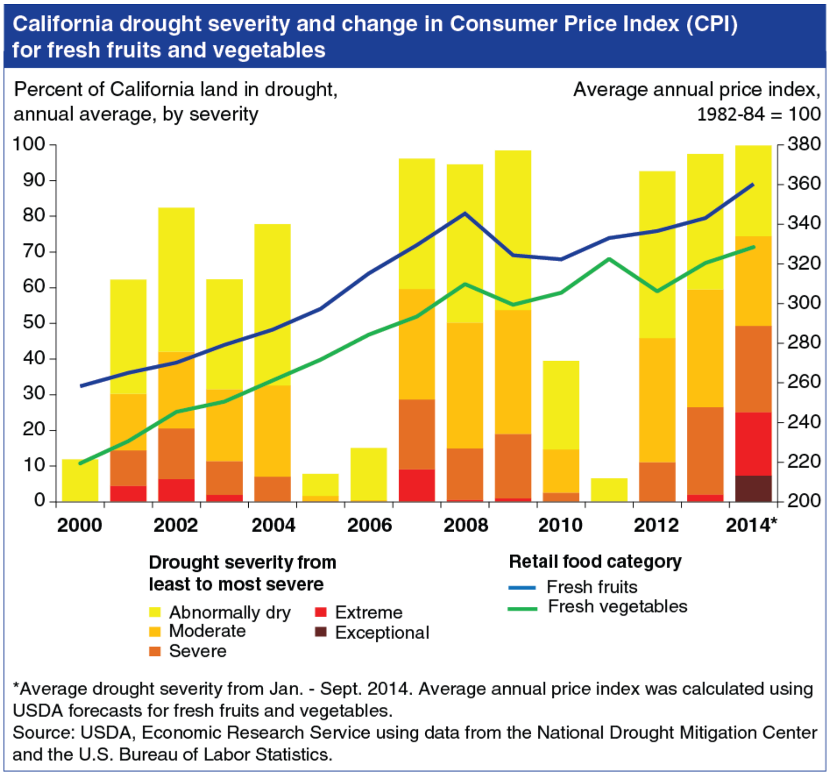
studies were used instead. Cotton, garlic, lettuce, melon, rice, and tomato were adjusted in this way.

If cost and return studies did not provide positive profits, values developed by Kaffka and Jenner, (2011) in an earlier use of BCAM were used and then adjust yield, price, and cost data to 2012 levels. The crops modeled in this way were broccoli, forage fodder (grass silage), oat hay, potatoes, sorghum, sudangrass, and sugarbeets.

When all the incumbent crops had positive profits, the crop data was organized by region and season, so that BCAM could be run to determine market entry prices and acreage for the potential biofuel crops.

Figure 39: California drought severity and change in Consumer Price Index (CPI) for fresh fruits and vegetables.

USDA_ERS: “In 2012, California produced nearly 50 percent (by value) of the nation’s vegetables and non-citrus fruit. Droughts in California are generally associated with higher retail prices for produce, but price increases are lagged due to the time it takes for weather conditions and planting decisions to alter crop production, which then influence retail prices. In 2005, following five years of drought, retail fruit prices rose 3.7 percent and retail vegetable prices increased 4 percent. Prices continued to rise in 2006, one year after drought conditions began to improve. However, other factors such as energy prices and consumer demand also affect retail produce prices. For example, prices for fresh produce fell in 2009 despite drought conditions, as the 2007-09 recession reduced foreign and domestic demand for many retail foods. As of October 2014, ERS analysts are forecasting fresh fruit prices to increase 4.5 to 5.5 percent in 2014 and vegetable prices to be 2 to 3 percent higher.”



California drought severity and change in Consumer Price Index (CPI) for fresh fruits and vegetables

*Average drought severity from Jan. - Sept. 2014. Average annual price index was calculated using USDA forecasts for fresh fruits and vegetables.
Source: USDA, Economic Research Service using data from the National Drought Mitigation Center and the U.S. Bureau of Labor Statistics.

Table 53: Yields, prices, costs, and irrigation levels of the incumbent crops in San Joaquin Valley.

The potential bioenergy crops are also included at the bottom of the table.

	Yield	Units	Price	Cost	Water (ac-ft)	Price & Yield Data Year	Cost Data Year
Alfalfa	6.9	tons	211	661	2	2012	2012
Barley	55	BU	5.97	166	0	2012	1995
Beans	2270	lbs	0.49	1048	3	2012	2013
Bermudagrass	7.83	tons	186	1001	6.5	2013	2013
Broccoli	575	box	12	6630	2.5	2007	2007
Carrot	310	cwt	26.9	6883	4	2012	2004
Corn	185	BU	7.05	1258	4	2012	2012
Cotton	1658	lbs	1.03	1321	2.5	2012	2012
Forage fodder	2.6	tons	148.61	371.96	0.5	2007	2007
Garlic	13800	lbs	0.41	4834.00	2.5	1992	1992
Lettuce	750	cartons	14.00	9451.00	1.5	2009	2009
Melon	16.68	tons	517.00	5672.00	5	2003	2004
Oat	2.6	tons	148.61	371.96	0	2007	2007
Potatoes	20	tons	140.00	2555.00	2.5	2007	2007
Rice	8110	lbs	0.15	734.00	7.5	2007	2007
Safflower	2100	lbs	0.21	330.00	0.5	2012	2011
Sorghum	5	tons	155.07	704.14	2.5	2007	2007
Sudangrass	5.3	tons	157.24	802.81	2.5	2007	2007
Sugarbeets	30	tons	41.93	1088.52	4	2007	2007
Tomato	48.99	tons	70.00	2354.00	3.5	2007	2007
Wheat	6	tons	156.00	875.00	1.5	2012	2013
Camelina	1600	lbs	0.16	636	0	2012	2012
Canola	2500	lbs	0.28	721	0	2007	2007
Grain sorghum	4.5	tons	155.07	704.14	2.5	2012	2012
Sugarbeet	43.7	tons	66.00	2793	4	2012	2007
Sugarcane	45	tons	47.00	2132.00	0	2012	2012

Table 54: Estimated cost per acre to produce canola in California (base year: 2012).

INPUT	Quantity (per Ac)	UNIT	Cost/Unit	Total
FERTILIZER				**$ 227.90**
Nitrogen (dry)	175	lb	$ 0.74	$ 129.50
Phosphorous (dry)	20	lb	$ 0.74	$ 14.80
Potassium (dry)	120	lb	$ 0.54	$ 64.80
Sulfur (dry)	20	lb	$ 0.94	$ 18.80
PESTICIDES				**$ 41.40**
Assure II	2	pint	$ 20.00	$ 40.00
Ammonium Sulfate	4	pint	$ 0.35	$ 1.40
SEED				**$ 48.00**
Canola	6	lb	$ 8.00	$ 48.00
LABOR				**$ 47.17**
Labor (Machine)	2.1	hrs	$ 16.08	$ 33.77
Labor (Non-machine)	1	hrs	$ 13.40	$ 13.40
FUEL				**$ 30.87**
Diesel	9	gal	$ 3.43	$ 30.87
REPAIR & MAINTENANCE				**$ 12.80**
Lubricants	1	Ac	$ 2.20	$ 2.20
Repair	1	Ac	$ 10.60	$ 10.60
CUSTOM & CONSULTANT				**$ 31.37**
Rental Sprayer	1	Ac	$ 2.16	$ 2.16
Custom Aerial Spray	1	Ac	$ 8.03	$ 8.03
Rental Ripper Shooter	1	Ac	$ 6.18	$ 6.18
Soil Test	1	Ac	$ 15.00	$ 15.00
OTHERS				**$ 266.53**
Overhead				$ 250.00
Crop Insurance				$ 10.00
Interest on Operative Capital				$ 6.53
Total Cost per Acre 2012				$ 706.04
Yield per Acre				2500 lb

Table 55: Estimate cost per acre to produce sugarcane in California (base year: 2012) (4-year production cycle).

Input	Total Cost per Acre
Seed	$1,016.10
Planting	$872.57
First Rattoon	$512.24
Second Rattoon	$512.24
Third Rattoon	$512.24
Fourth Rattoon	$512.24
Fertilization	$1,432.00
Irrigation	$1,157.32
Others	$2,000.00
Total per Acre 2012 (4 year period)	$8,526.95
Total per Acre per year 2012	$2,131.74
Total per Acre per year 2007	$1,948.85
Yield per Acre per harvest	45 Tons

Table 56: Estimated cost per acre to produce Camelina in California (base year: 2012) (4-year production cycle).

INPUT	Quantity (per Ac)	UNIT	Cost/Unit	Total
FERTILIZER				**$ 157.60**
Nitrogen (dry)	80	lb	$ 0.74	$ 59.20
Phosphorous (dry)	20	lb	$ 0.74	$ 14.80
Potassium (dry)	120	lb	$ 0.54	$ 64.80
Sulfur (dry)	20	lb	$ 0.94	$ 18.80
SEED				**$ 48.00**
Camelina	6	lb	$ 8.00	$ 48.00
LABOR				**$ 47.17**
Labor (Machine)	2.1	hrs	$ 16.08	$ 33.77
Labor (Non-machine)	1	hrs	$ 13.40	$ 13.40
FUEL				**$ 30.87**
Diesel	9	gal	$ 3.43	$ 30.87
REPAIR & MAINTENANCE				**$ 12.80**
Lubricants	1	Ac	$ 2.20	$ 2.20
Repair	1	Ac	$ 10.60	$ 10.60
CUSTOM & CONSULTANT				**$ 31.37**
Rental Sprayer	1	Ac	$ 2.16	$ 2.16
Custom Aerial Spray	1	Ac	$ 8.03	$ 8.03
Rental Ripper Shooter	1	Ac	$ 6.18	$ 6.18
Soil Test	1	Ac	$ 15.00	$ 15.00
OTHERS				**$ 266.53**
Overhead				$ 250.00
Crop Insurance				$ 10.00
Interest on Operative Capital				$ 6.53
Total Cost per Acre 2012				$ 594.34
Yield per Acre				1600 lb

Table 57: Estimated cost per acre to produce grain sorghum in California (base year: 2012).

INPUT	Quantity (per Ac)	UNIT	Cost/Unit	Total
IRRIGATION				**$137.40**
Water	30	acin	$4.58	$137.40
FERTILIZER				**$63.00**
80-0-0 (NH3)	140	lb N	$0.45	$63.00
INSECTICIDE				**$9.03**
Lorsban 15G	2	oz	$0.19	$0.38
Lorsban 4E	1	pint	$8.65	$8.65
HERBICIDE				**$43.41**
Yukon	6	oz	$3.80	$22.80
Prowl H20	3	pint	$6.87	$20.61
SEED				**$16.00**
Sorghum Seed	10	lb	$1.60	$16.00
LABOR				**$28.72**
Labor (Machine)	1.67	hrs	$13.94	$23.28
Labor (non-machine)	0.5	hrs	$10.88	$5.44
FUEL				**$31.01**
Gas	0.95	gal	$3.36	$3.19
Diesel	7.52	gal	$3.70	$27.82
REPAIR & MAINTENANCE				**$11.00**
Lubricants	1	ac	$5.00	$5.00
Repair	1	ac	$6.00	$6.00
CUSTOM & CONSULTANT				**$118.00**
Plant	1	ac	$20.00	$20.00
Injection-Sidedress NH3	1	ac	$14.00	$14.00
Harvest Combine Grain	4	ton	$14.00	$56.00
Harvest: Haul Grain	4	ton	$7.00	$28.00
OTHERS				**$251.00**
Overhead				$244.00
Interest on Operative Capital				$7.00
Total Cost per Acre 2009				$708.57
Yield per Acre				8,000 lb

Appendix C: Economic Modeling: Biomass Crop Adoption Model and IMPLAN

BCAM: A quadratic system of equations, which embody the previous information, is maximized (Eq. 1 and 2) for each cluster in each region. Then results are aggregated to determine the final outcome at a regional level.

$$MAX_{X_{i,land}}\begin{pmatrix}\sum_{i\neq Energy}[\{P_i(\beta_i-\omega_i X_{i,land})-C_i\}X_{i,land}]+\\ [\{P_{Energy}Y_{Energy}-C_i\}X_{Energy,land}]\end{pmatrix} \quad (1)$$

$$\text{subject to: } \sum_i X_{i,j}\leq \bar{R}_j\ \forall j = land\ and\ water \quad (2)$$

where P_i is the historical price of crop *i* and in the case of the energy crops (i.e. *i*=*Energy*) is the variable used for simulation, β_i is the intercept of the quadratic production function of crop *i*, ω_i is the slope of the quadratic production function of crop *i*, C_i is the cost per acre of crop *i*, $X_{i,j}$ is the amount of input *j* (land or water) that is used to produce crop *i*, Y_{Energy} is the expected yield of the new energy crop derived from recent agronomic research or from literature values, and $\bar{R}_j$ is the maximum amount of input *j* (land or water) available in the cluster of a region.

Model Construction in IMPLAN

Model

'Models' are the term in IMPLAN that identifies the analysis study area. Economic data enters the software in geographic units such as states and counties. The "Model" refers to the geographic boundaries in specific models. The economic impact is influenced by the size and economic footprint of each geographic boundary. The models are developed to measure the economic impact of each of these biorefineries within each county, i.e. in Fresno, Imperial, and San Joaquin Counties in California.

Scenarios

IMPLAN Scenarios are described as 'containers for activities. They represent an implementation or calculation of the economic impact based on the events and activities established within each scenario.

Activities

IMPLAN activities serve as the containers for one or more events. Activities involve specific changes in economies such as expanded production, new facility construction, or operation of a newly constructed facility. The activities included in the economic impact analysis include: (1)

biorefinery construction; (2) canola seed or sugar beet or sugarcane production depending on the type of plant analyzed; (3) the production of co-products such as biogas or glycerin; (4) the operation of the biorefinery; and (5) the production of the biofuel.

Event

IMPLAN events identify specific industries that are involved in each activity and the levels at which they are involved. There is flexibility in how the events are quantified. For example, sugar beet production was based on increased profit per acre of sugar beet grown. The sugar beet production activity is represented by industry number 9: Sugarcane and sugar beet farming; canola seed production is represented by industry number 1: Oilseed farming; and sugarcane production is represented by 9: Sugarcane and sugar beet farming. The construction of the biorefinery activity is represented by industry number 36: Construction of other new nonresidential structures. The operation of the biorefinery activity has multiple events and they include the ethanol production (represented by industry number 49 Beet sugar manufacturing) or biodiesel production (represented by industry number 45 Soybean and other oilseed processing) and the co-production of biogas (represented by industry number 31 Electric power generation, transmission, and distribution) or glycerin (represented by industry number 46: Fats and oils refining and blending). IMPLAN requires an analogous industry to be chosen to model the events in our scenario analysis. These industries have been selected because they most closely resemble the new enterprises being analyzed, but results are only an approximation of actual effects of a new first-of-kind business in the region.

Event Year

The data that was used for this analysis was created for the calendar year 2010. Since prices vary with time, the year for which the various events are set matters. In this economic analysis, the construction of the biorefinery was set in 2014. The other annual activities of the biorefinery plant operation and crop production (e.g. sugarcane, sugar beet, and canola) were modeled as taking place in 2015.

Appendix D: Transformation Systems for Agricultural Biomass Likely to Be Used in California

Summary

The new biorefineries likely to be developed in California to support the use of in-state feedstock use are likely to adopt well-known technology, have lower capital costs than more sophisticated processes focused on cellulosic or other low quality feedstocks, and are likely to be available in the near-term for installation. Combined with high yielding, high quality and readily transformed feedstocks like sugar and oil crops, the opportunity exists to develop several new or expanded bioenergy systems in the state. Some of the proposed project also generate power from direct combustion of residues, (sugarcane) or from biogas production from silage or other residual material (sugarcane, energy beets, grain sorghum), or produce glycerin, which can be used in anaerobic digester systems (biodiesel).

Biochemical Pathways

A range of oilseed, sugar, grain, and cellulosic feedstocks may be used by in-state bioenergy producers. The most likely ones are reviewed here and evaluated based on readiness and cost.

Vegetable Oils to Biodiesel

The characteristics of biodiesel fuels derived from vegetable oils or fats and greases depend on the fatty acid composition of the feedstock source (Knothe, 2005). In general, the shorter the fatty acid carbon chain length, the more readily the resulting biodiesel fuels will tend to solidify in cold weather (at a temperature called the cloud point), and also exhibit oxidative instability leading to water formation and other undesirable changes with storage. Fats, oils, and greases (FOG) generally have shorter chain fatty acids and free fatty acid contaminants and are more difficult to be converted into high quality biodiesel than vegetable oils using the most common process, called FAME (discussed below). Alternatively, they are subject to hydrocracking in which they are converted to esters with the addition of hydrogen and are made into green diesel or renewable diesel. These fuels are largely indistinguishable from conventional petroleum diesel. In a similar manner, they can serve as a source for biojet fuel (discussed below). Vegetable oils with a large amount of oleic fatty acids (18:1) generally can be converted into well-performing biodiesel with a lower cloud point and better oxidative stability, and are desirable feedstock sources.

Typical oil composition of the oilseed crops investigated here and comparisons with safflower (commonly produced in California) are presented in Table 58.

Table 58: Typical fatty acid composition of vegetable oils, with data from diverse sources.

Principal Fatty Acids									
Species	16:0 Palmitic	18:0 Stearic	18:1 Oleic	18:2 Linoleic	18:3 Linolenic	20:00	20:1*	22:0; 22:1	22:2**+> 22:2
Canola (Br. Napus)	6.20	0.00	61.30	21.60	6.60				
Rape Seed	3.50	1.40	60.00	20.50	10.00		0.90	0.20	
Indian Mustard (B. Carinata)	7.80	3.00	16.80	23.00	31.20				
Camelina	20.70	6.10	53.50	9.80			12.00	2.80	
Meadowfoam	0.60	0.20	1.00	0.90		0.80	64.20	10.40	19.50
Safflower	5.00	<1.00	77.00	15.00					

The protein-rich meals remaining after oil extraction are valuable livestock feeds and can be further converted into other products, including, in some cases, biopesticides.

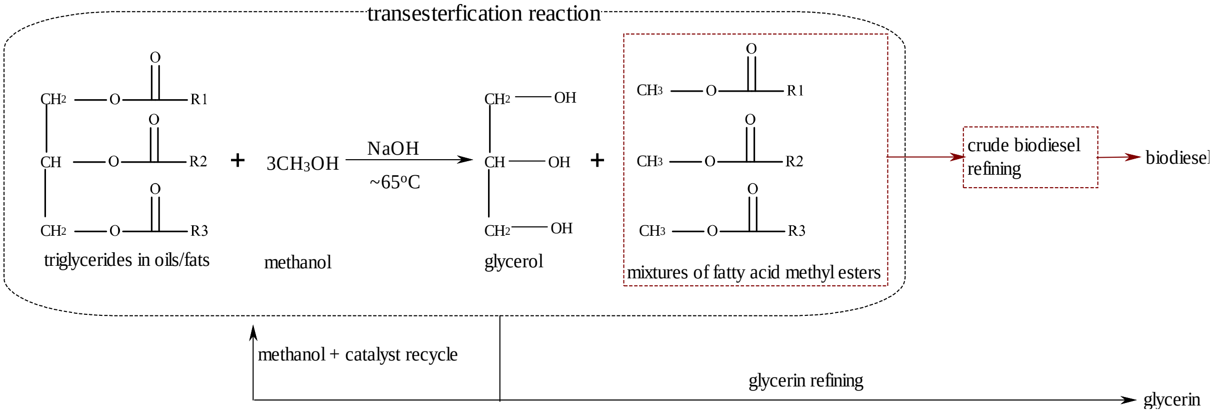
Fatty Acid Methyl Ester (FAME) Process

Fatty acid methyl esters (FAME) are long-chain mono alkyl esters converted from oils or fats, also called biodiesel. As shown in Figure 40, the core technique of the FAME process is a transesterfication reaction between methanol and triglycerides, which contain three fatty acids in vegetable oils, animal fats, or recycled cooking oil. A transesterfication reaction is reversible and carried out with either strong base or acid catalysts at low temperature and pressure conditions. At an industrial scale, sodium hydroxide or potassium hydroxide is the catalyst most used because of its low cost. Methanol is mostly used for the transesterfication process due to advantages of low cost and easy post-reaction separation from glycerol residues compared to other alcohols. If anhydrous ethanol were available at low cost, it could be used as well. To achieve nearly complete conversion of triglycerides, excessive methanol (4.5 to 6 molar ratios to triglycerides) must be employed in the transesterification reaction, which results in high yields (~95% of fatty acid methyl esters). However, excessive methanol also affects subsequent separation of methanol from glycerol (Figure 40).

Overall, the FAME process is a relatively simple technique and has modest capital costs, which allows for small production units to be built without excessive extra costs. Smaller units can be located nearer to sources, with potential savings from reduced feedstock transportation and other related logistical costs. This basic process for biodiesel production has been successfully employed for many different vegetable oils, fats, and other feedstocks. However, the FAME process has very limited scope for modifying FAME biodiesel properties since the structures of fatty acids including unsaturated carbon-carbon bonds and the oxygen content remain unchanged. Therefore, the properties of biodiesel produced via the FAME process are highly dependent on the composition of the feedstocks. In this case, the distribution of fatty acids in the vegetable oils or fat quality determines the properties of its biodiesel. For example, the cetane number increases with longer C chain fatty acids, and with more saturated C bonds (Gerpen, 1996).

Canola oil, Camelina oil, and meadowfoam are useful feedstocks for biodiesel production for the FAME processes. However, the compositional differences among these three oils resulted in the corresponding qualities of biodiesel as the fatty acid profiles in the oils transfer to biodiesels. As a commercially available source, canola oil has 92.6% unsaturated C18 fatty acids (63.9% C18:1, 19.0% C18.2, and 9.7% C18.3) and less than 2% erucic acid (Sanford, 2009). Compared to canola oil, Camelina oil has more carbon-carbon double bonds, since the largest portion of unsaturated C18 fatty acids is C18:3 (37.9%) and 73.6% unsaturated C18 fatty acids (17.7% C18.1, 18.0% C18.2, and 37.9% C18.3), as well as 11.4% unsaturated C20 fatty acids (9.8% C20:1 and 1.6% C20:2) and 4.5% unsaturated C22.1 fatty acids, which resulted in lower oxidative stability and higher cold soak filtration[53] (223 s) values versus 113 s of canola biodiesel (Sanford, 2009). Overall, Camelina biodiesel is comparable to canola oil for average oil quality values, but less is known about variation in oil quality by variety and location.

Figure 40: Diagram of the simplified FAME process.



There are thirteen companies producing biodiesel in California in 2013. Most use residual FOG, but some also use vegetable oils derived from diverse sources. Total in-state capacity varies between 30 and 60 mgy. The state has emphasized the use of FOG through support from its AB 118 program.

Renewable Diesel and Biojet Fuels from Vegetable Oils

Instead of the esters that comprise biodiesel, renewable diesel or jet fuels can be made by hydrogenation and deoxygenation of vegetable oils, resulting in hydrocarbons that can be added to petroleum-based fuels with mostly similar properties avoiding blending limits. Low-cost H_2 is needed to produce biodiesel esters. H_2 is commonly available at petroleum refineries and Neste Oil, Inc. and others have created such facilities in Europe and Indonesia. In California, both Crimson Industries and Alt Air, Inc., have investigated or proposed using this pathway.

The process for renewable diesel production includes hydrogenation and deoxygenation of vegetable oils and animal fats, which is similar to those used at a petroleum refinery. The catalysts usually include metals, such as nickel or platinum, and base materials, such as carbon, alumina, and zeolite (Snåre, 2007). Generally speaking, the most effective catalyst is composed of costly metals, such as platinum. The choice of an economically effective but less costly catalyst, such as Raney nickel, for hydrogenation and deoxygenation, is very critical for the economic optimization of the process (Munoz, 2012; Horáček, 2013). The deoxygenation results in an increase of energy content. Because hydrogenation eliminates carbon-carbon double

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[53] http://enterprise.astm.org/filtrexx40.cgi?+REDLINE_PAGES/D7501.htm

bonds, the fuel cetane number (CN)[54] is improved. When the hydrogenation is controlled, as partial or full hydrogenation with deoxygenation, the melting point is modified for good low temperature properties. The techno-economic analysis for hydrogenation-derived renewable diesel from canola and Camelina showed the largest component of total oil production costs was feedstock cost (75-85%) including harvest, and on-farm storage (if any). However, seed transportation costs will have a greater effect on overall oil cost as plant size increases. Therefore, the optimum plant size was most sensitive to transportation cost for feedstocks, capital and operation cost; resulting in little economic benefit for plants larger than 5,000 bbl/day (Miller, 2012). There is interest in making biojet fuels from vegetable oils as well, which require decarboxylation of free fatty acids followed by catalytic isomerization/cracking to make n-alkanes with C chain lengths of C10-C14 in order to achieve the required chemical and physical properties of biojet fuels. Besides biodiesel and biojet fuels produced via this process, low chain length alkanes could be used for the production of biogasoline (primarily hexane and its isomers). Alt Air has investigated the production of jet fuel from Camelina oil. Federal policy favors the use of non-food oils over those with potential use for food, even if such feedstocks are significantly less efficient to produce than edible oil crops.

Sugar to Ethanol

Besides biodiesel, bioethanol is the other important liquid transportation fuel widely used. Bioethanol is currently made from common crops including sugarcane and corn at large scale. In the future, lignocellulosic sources may become more important, due to its abundance in nature. Biofuel and biochemical production from agricultural crops are based on the production of the monomeric sugars from biomass. Sweet sorghum and sugarcane store in their stems soluble carbohydrates produced from photosynthesis primarily as six-carbon sugars and, in the case of sweet sorghum, additional five-carbon sugars. These are removed by crushing and expressing plant juices, which are either purified and crystalized as sugar, or fermented using yeast to ethanol. These crops also accumulate large amounts of lignified cellulosic biomass as stems and leaves. Converting lignified cellulosic compounds to simple sugars requires additional treatments. Both C6 and C5 sugars can be derived from lignified crop residues by decomposing cellulose using various pre-treatment methods. Depending on the conversion technology used, different mixes of C5 and C6 sugars of varying purity can be produced.

Sugarcane Conversion

In contrast to corn ethanol in the USA, sugarcane ethanol is well established in Brazil, where it is the primary source of renewable energy (15.4% of fuel supplies), second only to petroleum and its derivatives (39.2%). A typical sugarcane ethanol plant in Brazil costs USD 150 million,

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[54] Cetane number is a measurement of a fuel's ignition delay, the time period between the start of injection and the first identifiable pressure increase during combustion of the fuel. ASTM D613-13 http://enterprise.astm.org/

and processes 2 million tons of sugarcane per year, based on 30,000 hectares of land, and produces 200 million liters ethanol (Chum et al., 2014; Goldemberg, 2008). Based on sugar content of the juice alone, energy budget analysis under sub-tropical Hawaiian conditions (Ming et al., 2006) suggested that an energy input: output ratio of 1: 3 is attainable for ethanol from commercially produced sugarcane sugar. In Brazil's highly developed sugarcane/ethanol economy, the analogous input: output ratio is 1: 9 (Macedo, 2000; Ming et al., 2006). In contrast, maize fermentation to ethanol exhibits a ratio below about 1: 1.5, and is often less (U.S. DOE, 2007). Inclusion of lignocellulosic material will increase this substantially.

Calculations based on Keffer et al. (2009) and Waclawovsky et al. (2010) estimate the potential yields of lignocellulosic fuel ethanol from sugarcane. Based on sugarcane bagasse, assuming that 14% of stalk biomass is sugar and 70% of fresh cane is water, and that yields in the Imperial Valley of 45 ton acre^{-1} at 70 % moisture and 12-14% Brix may be sustainable with suitable agronomic practices, a yield of approximately 9 m^3 of EtOH ha^{-1}, or about 960 gallons of EtOH acre^{-1} appears feasible in California. This is larger than other potential or current sources of ethanol from crop-based feedstocks except sugar beet.

Lignocellulosic technology is not yet commercial, and the optimum end product, EtOH, may evolve to butanol, which is not subject to the same blending limits as ethanol. Several other technologies are in development in California and elsewhere (Lynd et al., 2008). Candidate technologies for the production of advanced biofuels in California include deconstruction using thermophilic bacteria (maximum growth temperatures of ~70°C; Cann, 2010). Alternative technologies include chemical deconstruction by hydrodeoxygenation (dehydration-hydrogenation) processes (Ellman, 2010). Molecular genetic modification of the energy cane itself may facilitate commercialization of these approaches. Combinations of these approaches (Ferreira-Leitão et al., 2010; Yang and Wyman, 2006, 2008; Chu, 2010) will ultimately lead to the utilization of sustainably produced lignocellulosic biomass from energy cane and other regionally appropriate feedstocks. Some of these processes are beginning to reach commercialization, but at high initial cost.

Traditionally, sugarcane residues (bagasse) have been burned at sugar or ethanol refineries for power. Waste heat has not been captured for other uses. More recently, there have been efforts in Brazil, where most sugarcane is produced, to use residual bagasse for ethanol or biochemical production as well, including capturing some waste heat for biorefinery uses (Alvira et al., 2010). California Ethanol and Power[55] has proposed building a modern biorefinery in the Imperial Valley based on this technology using bagasse to produce steam and electricity along with the fermentation of the extracted juice to ethanol.

Based on the sugar content of the juice alone, energy budget analysis under sub-tropical Hawaiian conditions suggested that an energy input: output ration of 1: 3 is attainable for ethanol from commercially produced sugarcane sugar (Ming et al., 2006). In Brazil's highly developed sugarcane/ethanol economy, the analogous input: output ratio is 1: 9 (Macedo, 2000;

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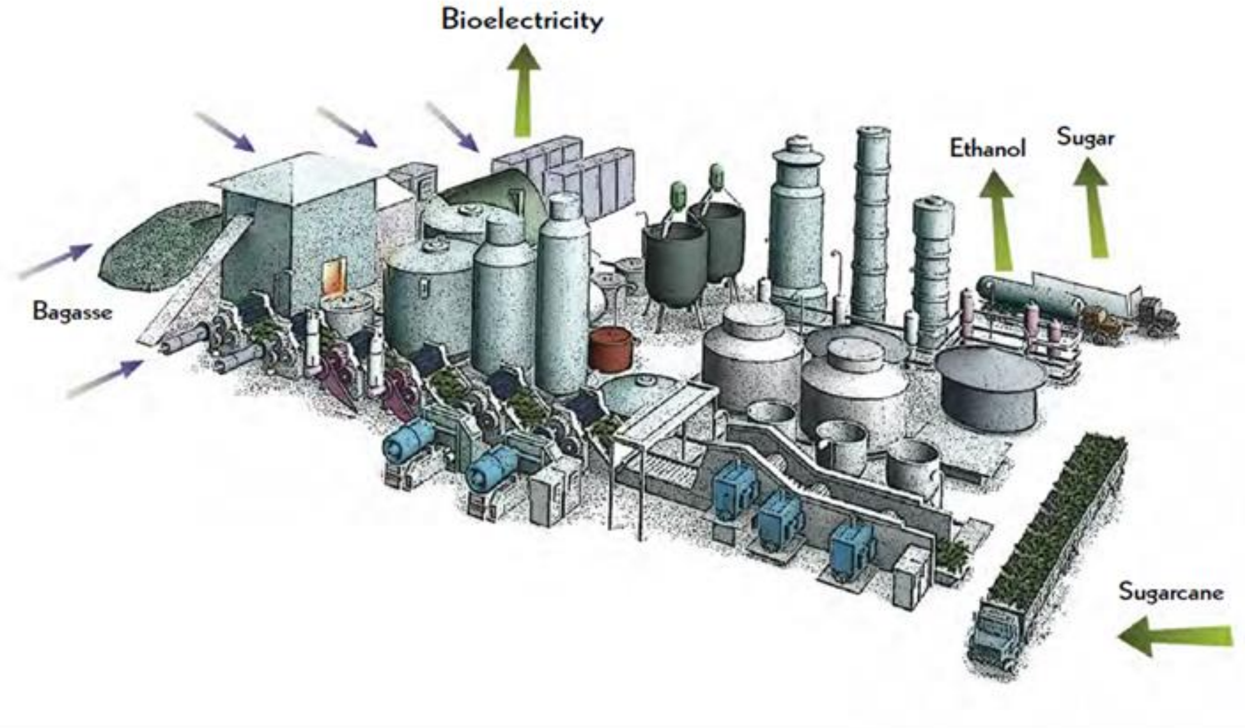
[55] http://www.californiaethanolpower.com/

Ming et al., 2006). In contrast, maize fermentation to ethanol exhibits a ratio below about 1: 1.5, and is often less (U.S. DOE, 2007), though efficiency has been increasing and the use of maize results in large amounts of high quality animal feed by-products (DDGS) and oil that is made into biodiesel or used for feed. Inclusion of lignocellulosic materials like corn stover will increase this energy efficiency substantially. Three small commercial scale cellulosic ethanol projects are scheduled to open in the Midwest in the next months that will use corn stover as a feedstock and be attached to starch (grain) based facilities.

Figure 41: Modern sugarcane refinery in Brazil Source: Unica.

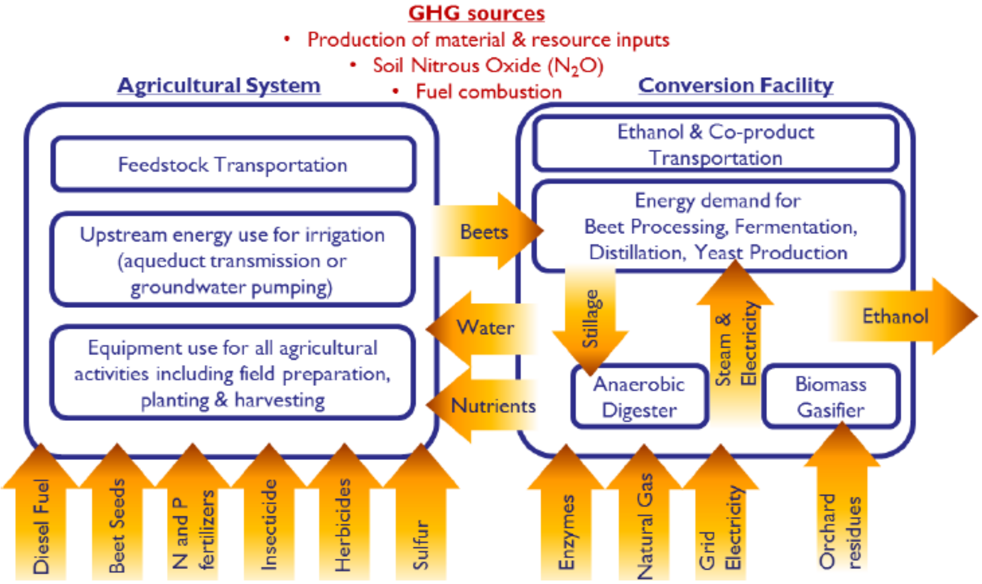


Energy (Sugar) Beets to Ethanol

Two processes have been discussed in California. The first resembles traditional sugar extraction followed by refining to ethanol and the production of beet pulp feeds from residual beet root biomass (Tracey). This process is similar to beet ethanol production attached to sugar factories in Europe and is the process analyzed in USDA’s and other economic and feasibility studies (Bowen et al., 2010; Krajnc & Glavic, 2009; Munoz et al., 2014; Schweitzer, 2006; Shapouri et al., 2006). The second is a more novel approach and by-passes sugar diffusion, and instead ferments ground whole beets and a portion of the beet fiber to ethanol with biogas, water and fertilizer produced as co-products or as an alternative livestock feeds. It relies on the liquefaction of sugar beets ready to ferment sugars to ethanol, a new pathway). After washing, the beets are sliced to coarse cossettes, and sent to a grinder pump rather than to a thermal diffusion step in traditional sugar factories. The ground beet solids in suspension are conditioned in a slurry tank ready for liquefaction with enzymes. The substrate after liquefaction undergoes enhanced simple fermentation to produce ethanol. Ethanol is then distilled and the stillage can be re-fermented with other residual components such as cellulose and hemicellulose. The final stillage can be used as a feedstock for anaerobic digestion and biogas and further used as fertilizer.

Figure 42: Initial proposal for ethanol and other forms of energy production from beet crops in the San Joaquin Valley.

Three technologies are depicted: biomass gasification, ethanol production using yeast, and anaerobic digestion. Both power and fuel are produced. Alexiades, 2014.



Celluosic Crops and Residues to Ethanol and Other Fuels

Candidate technologies for production of advanced biofuels in California include deconstruction using thermophilic bacteria (maximum growth temperatures of ~70˚C (158˚F; Cann, 2010). Alternative technologies include chemical deconstruction by hydrodeoxygenation (dehydration-hydrogenation) processes (Ellman, 2010). Molecular genetic modification of the energy cane itself may facilitate commercialization of these approaches. Combinations of these approaches (Ferreira-Leitão et al., 2010; Yang and Wyman, 2006, 2008; Chu, 2010) will eventually allow for increased use of lignocellulosic biomass. Energy cane (*S. spontaneum*) would be used primarily for cellulosic conversions and cellulosic biofuels[56]. Canergy, Inc. has

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[56] Based on Keffer et al., (2009) and Waclawovsky et al, (2010), the potential yields of lignocellulosic fuel ethanol from energy can be estimated.

proposed an energy facility in the Imperial Valley based on the Proesa ™ technology discussed below[57]. Lignocellulosic technology is in its earliest stages of commercialization. Chemtex, in partnership with Beta Renewables, has an operating facility in Crescentino, Italy, based on the use of wheat straw that produces 13 M gal/y. This same technology is proposed for a site in North Carolina based on the use of *Arundo donax*, and in the Imperial Valley based on energy cane (*S. spontaneum*) and some perennial grass hay.

The Proesa™ technology is now being used to produce cellulosic ethanol at an industrial scale. The first commercial scale facility is operating in Crescentino, Italy, based on wheat straw and some perennial grass hay[58]. Canergy, Inc. LLC, an Imperial Valley-based company, may adopt this technology. The cellulosic biomass is treated by steam and water in order to reduce subsequent chemical costs and minimize sugar degradation products in the raw biomass, which could decrease overall sugar recovery and cause inhibition in the subsequent hydrolysis and fermentation stages. Steam and water pretreatments are optimized for overall sugar recovery. The core technology of the Proesa™ process is hybrid hydrolysis and fermentation with an engineered microbial strain that converts both C5 and C6 sugars to ethanol with a high final concentration. This technology is an example of consolidated processing, similar to the concept of Consolidated Bioprocessing (CBP) (Lynd, 1996, 2005). Compared to NREL’s multi-step cellulosic ethanol production system (Humbird, 2011), a solid-liquid separation step after pretreatment was removed in the CBP system and separate fermentation steps for C5 and C6 sugar were replaced with co-fermentation (hybrid fermentation) of both C5 and C6 sugars. This simplification effectively reduces both capital and operational costs, as shown in Figure 43.

Eq. (3) 1 metric ton hectare^{-1} = 0.45 ton acre^{-1}

Eq. (4) m^3 EtOH = (ton cane)

× {(0.14 ton raw sugar/ton cane) [(0.96 ton fermentable sugar/t raw sugar)

+ (0.276 t molasses/ton raw sugar) (0.482 t fermentable sugar/ ton molasses)]

× (0.588 m^3 EtOH/ton fermentable sugar) +

[(0.3 ton stalk fiber– 0.14 t sugar) / ton cane

+ (0.65 ton trash fiber/ ton stalk fiber) (0.3 ton stalk fiber/ ton cane)]

× (0.292 m3 EtOH/ton fiber)}

The first term in Eq. (2) gives ethanol (EtOH) from sugar, the second term gives EtOH from molasses, and the third term gives cellulosic ethanol from the remaining biomass (bagasse, field trash, attached leaves, etc.).

[57] http://www.canergyus.com/

[58] http://www.biofuelsdigest.com/bdigest/2013/06/11/beta-renewables-begins-shipping-cellulosic-biofuels/

Figure 43: Proesa TM technology in Italy. Rubino, 2012.

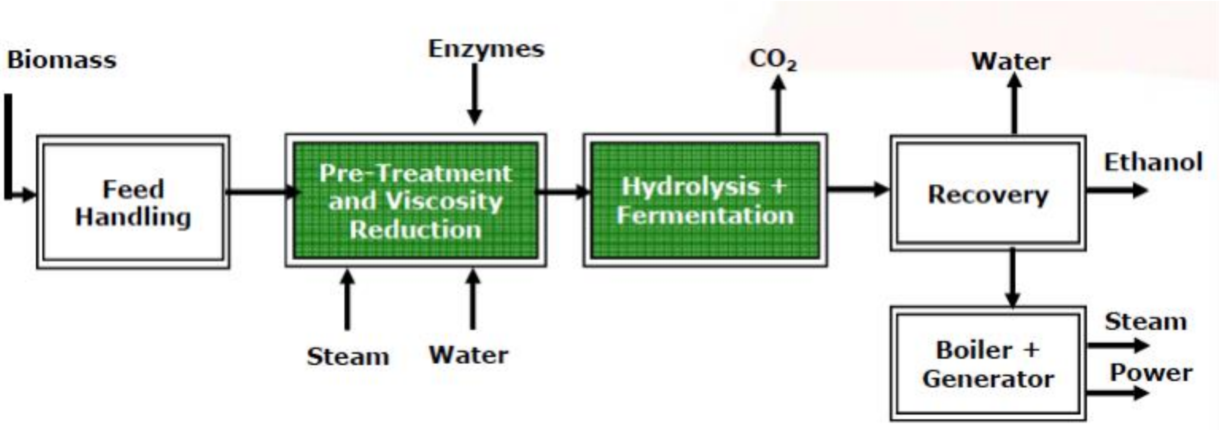

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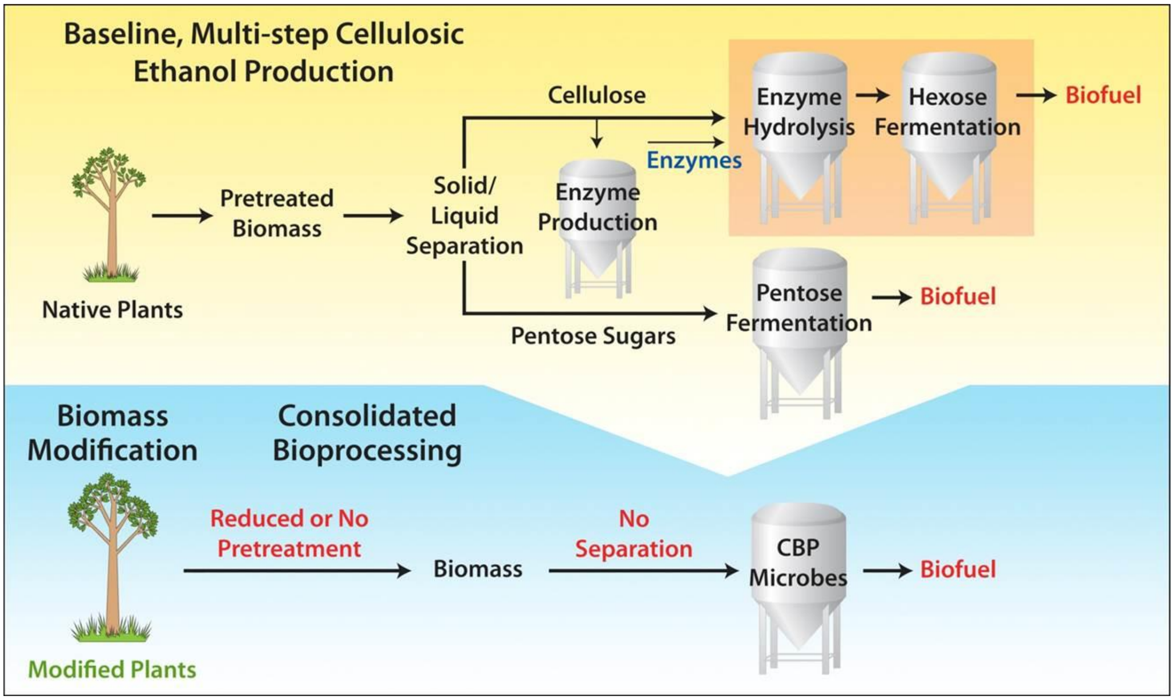
Figure 44: Chemtex facility (Crescentino, Italy, 20 mgy)

Figure 45: Consolidated bioprocessing next generation biofuel process (BESC). Sweet sorghum, sugar, and energy cane.



Biofuel and biochemical production from agricultural crops is based on the production of monomeric sugars from biomass. These are primarily soluble and removed by crushing and expressing plant juices. They also accumulate large amounts of lignified cellulosic biomass as stems and leaves. Converting lignified cellulosic compounds to simple sugars requires additional treatments. Both C6 and C5 sugars are derived from crop residues. Depending on the conversion technology used, different mixes of C5 and C6 sugars of varying purity can be produced.