Bioenergy Production Pathways and Value-Chain Components

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Report on Bioenergy Analyses

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Bioenergy Production Pathways and Value-Chain Components:

Assessing Pathways Relevant to Hawaii Conditions

December 2012

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CONTENTS

Introduction:

The purpose of this report is to better understand the bioenergy pathways and value-chain components that can be used to expand the future use of bioenergy in the State of Hawaii. The Hawaii Bioenergy Master Plan identified a need for life-cycle analysis (LCA) as an important and valuable analytical tool that is needed to support decision making among both policy makers and various business and commercial interest stakeholders. This report will provide information on the various pathways that convert biomass feedstock into usable forms of energy, the conditions that make Hawaii unique and the pathways and value chain components relevant to Hawaii's conditions, the use of LCA methodology to track costs and impacts associated with the various pathway or value chain components, and the existing LCA information in the public domain and their relevancy to the objectives in the Master Plan. Through the identification of the potential pathways, value-chain components, and discussing the information on LCAs to date, readers can gain an appreciation for the technology and infrastructure developments that will be needed to enable market transformations, reduce risk, and increasing the potential for success.

Background:

Biomass has a long history as an energy resource, dating back to man's first use of wood fires to provide warmth, light, and an increased level of security and protection. There is archaeological evidence that outcrop coal was first used during the Bronze Age[1], 3,000 to 4,000 years ago, thus starting man's long transition to more convenient and energy dense resources. For centuries, demand for energy grew in a localized and organic way with people using resources that were conveniently available to them, included indigenous bio-based resources including peat, dung, plant-oils, bees wax, rendered animal fats, draft animals, natural derived sources from wind and water, and other convenient resources. These organic energy resources enabled tremendous societal advances, but as the saying goes, "from humble beginnings come great things".

During the period from 1750 to 1850, significant advances in agriculture, manufacturing, mining, transportation, and technology, were achieved, thus influencing a broad series of inflection points affecting social, economic and cultural standards. The industrial age had arrived marking a major turning point in history; and ushered in unprecedented gains in human development, from life expectancy to per capita income, to education and beyond – nearly every aspect of daily life was influenced in some way. As noted by Nobel Prize winning Economist Robert E. Lucas, Jr. [2], "For the first time in history, the living standards of the masses of ordinary people have begun to undergo sustained growth...Nothing remotely like this economic behavior has happened before". With the benefit of hindsight, we now know that industrial age advances also affected an inflection point on our demand for energy, and has resulted in the release of billions of tons of heat-trapping greenhouse gases to the atmosphere. Figures 1 and 2 illustrate historical information on the U.S. Primary Energy Consumption and Global Greenhouse Gas Emissions with the Industrial Age time period clearly denoted.

[1] a b Britannica 2004: Coal mining: ancient use of outcropping coal.
[2] Lucas, Robert E., Jr. (2002). Lectures on Economic Growth. Cambridge: Harvard University Press. pp. 109–10. ISBN 978-0-674-01601-9.

Figure 1: U.S. Primary Energy Consumption Estimates by Source 1775-2010

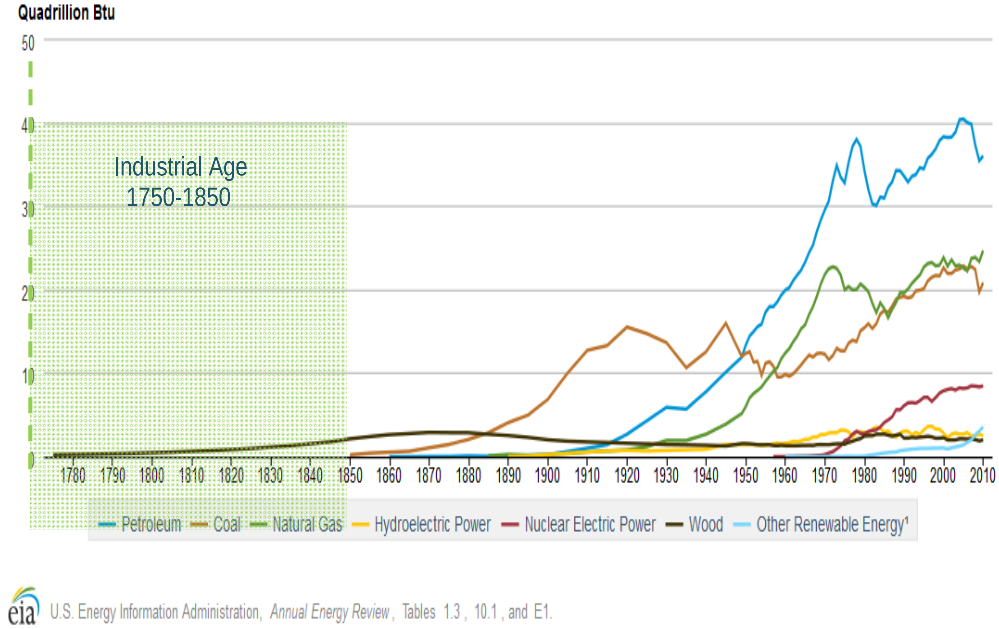
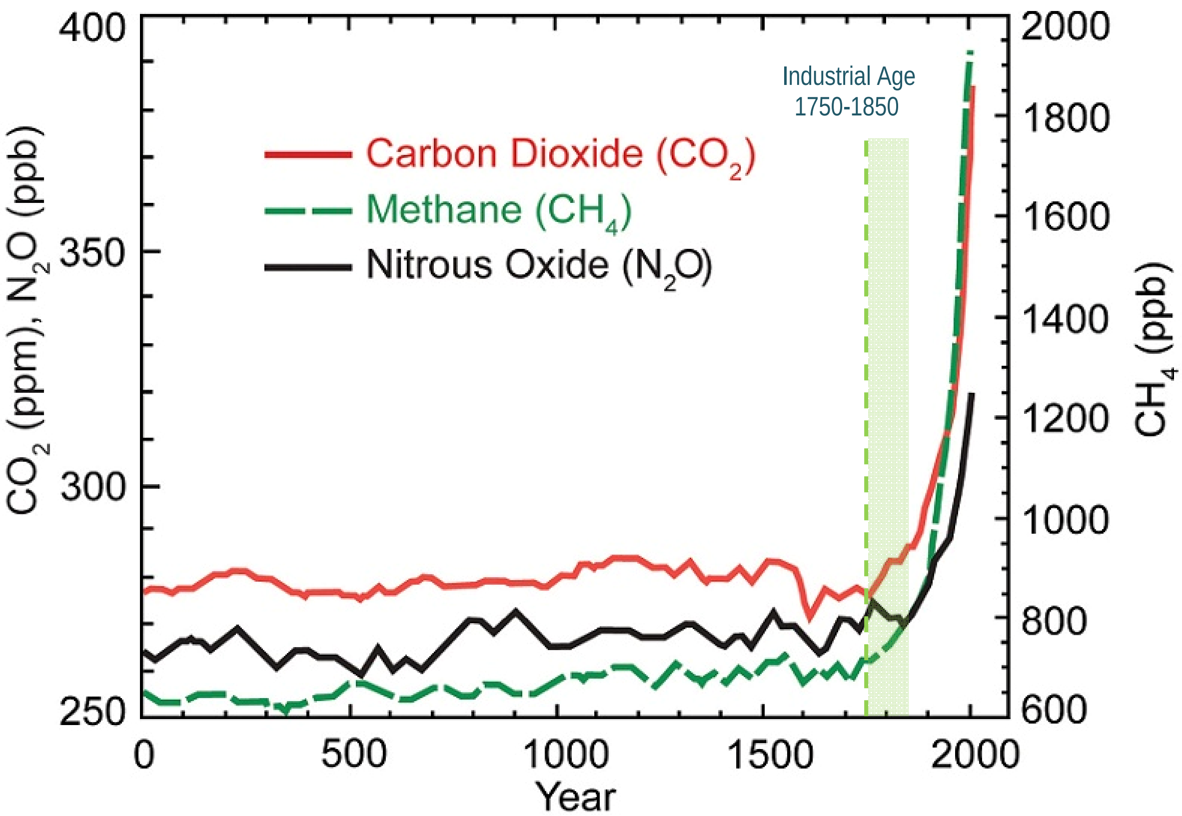


Figure 2: 2000 Years of Global Atmospheric Greenhouse Gas Emissions
2009-global-climate-change-impacts-in-the-united-states



Public debate over the relevancy of this information continues; including the question of whether the accumulation of climate changing GHG emissions (illustrated in figure 2) are the result of the human activity. And, while the debate continues, opportunities for biomass-derived fuels and products have reemerged as a near-, mid-, and long-term solution strategies for the reduction of GHG emissions, and as a means to address energy import and security concerns. The utilization of biomass-derived fuels is recognized as a critical component in the nation's strategic plan to address our energy security and oil dependence concerns. Given that the State of Hawaii has no indigenous fossil fuel resources of its own, the development of a biomass-derived fuels production capacity offers a clear opportunity to improve State and local economies, create jobs, and improve the energy supply and security situation. The use of pathway and life cycle analyses are proven and useful tools for organizing and conducting comparative analysis, across the full fuel supply chain, and will add critical information to the decision making process.

Literature Search

Information gathered for this report was obtained by performing web-based literature searches using web browsers and JSTOR accounts. The effort consisted primarily of literature search and office work to read the information, analyze results, and prepare report information and graphical elements.

Literature review for information to define the relevant to Hawaii conditions used reference data and information from a multitude of information and data sources from both the U.S. Government, and the State of Hawaii Government. Information on LCA and pathways analysis used sources from the U.S. Department of Energy, Argonne National Laboratory (ANL) Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model for a significant portion of the required life-cycle cost analysis information, as well as carbon emissions data for the various feedstocks and fuels. A great deal of information has been generated to date as a result of the State of California, implementation of a Low Carbon Fuel Standard (LCFS). The information prepared for the LCFS is fairly well documented. This information was used to develop the detailed information on the representative pathways and value chain components. Detailed review of the LCA published results proved difficult to compare with one another because of differences in scope, data presented, reference year, technology considerations, and other critical analytical factors. As such no effort was made to hybridize the information from multiple sources or capture it for a uniform basis for comparative study. The LCA information is best considered in their entirety and interested parties are encouraged to access and review these studies separately.

Information on feedstocks that can be cultivated in the State of Hawaii were gathered from all available sources including the State of Hawaii, Department of Business, Economic Development & Tourism (DBEDT), U.S. Department of Energy (DOE), Energy Information Administration (EIA) and Office of Biomass Programs (OBP), U.S. Department of Agriculture, and other sources deemed applicable. A landmark study by Oak Ridge National Laboratory on biomass feedstocks for use in biofuel production was recently updated. This report titled the Billion Ton Study[3], proved of little use in this effort because the information contained in the

[3] Billion Ton Study, Updated August 2011; web asscessible http://www1.eere.energy.gov/biomass/pdfs/billion_ton_update.pdf

report was geared toward the continental U.S land mass. Some information could be gleaned from the report to support an understanding of various species that could be cultivated in the state of Hawaii, but ultimately the information in the report does not significantly augment the knowledge base on feedstocks considered in the study scope.

Building an Analysis Framework:

A fundamental requirement in pathway analysis is to development an analytical framework for estimating life-cycle costs and environmental impacts. Once established, an objective and comparative normalized analysis of these pathways can be undertaken with the intent of identifying technologies with the greatest potential for meeting cost and environmental metrics. The advantages of performing pathway analysis, includes:

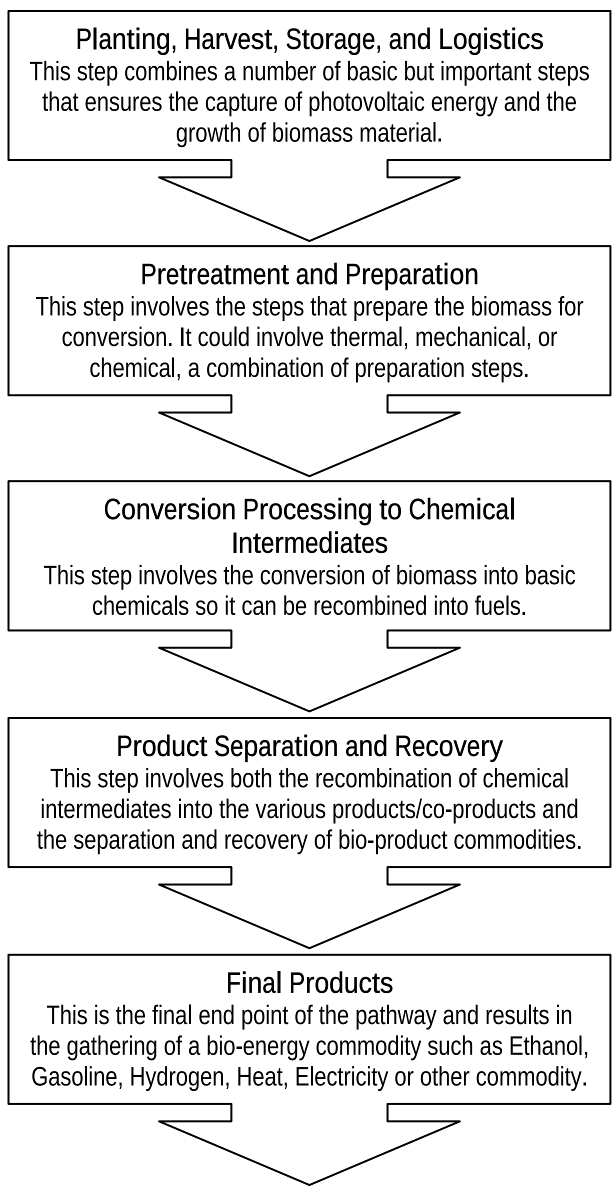
- Accessing economic competitiveness of a project or concept can be completed by evaluating the costs of the processes and comparing the results to current commercial technology options.
- Determining which concepts have the highest potential for near-, mid-, and long-term success.
- Enabling analysis useful in directing research toward specific technical areas in order to identify opportunities for research and development improvements that can achieve future largest cost reductions.
- Scaling of analysis appropriate to the technical maturity of the technologies under consideration and the amount of data that is available.

To ensure use of a consistent analytical framework in the analysis, this effort focused on the review of data from the U.S. Department of Energy, Argonne National Laboratory (ANL) Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model for all life-cycle cost analysis information, as well as carbon emissions data for the various feedstock and fuels. A great deal of information has been generated to date as a result of the State of California, implementation of a Low Carbon Fuel Standard (LCFS). The information prepared for the LCFS is fairly well documented and was thought to be an excellent resource for this study. Information from these model runs offer an opportunity for analysis and evaluation without the need for any additional groundbreaking analysis which was outside the scope of this effort. Graphical representations for all of the identified pathways will be presented in such a manner as to clearly communicate the relationships between the various value-chain components.

Consistent with the pathway analysis methodology, all pathways represented in this report have a logical and consistent start and terminal points, and progress from start point, through a set of critical processing steps, and arrive at their terminal point. For the purposes of this report, all pathways start with biomass a biomass feedstock, and end with the final energy product. This assumes that all land ownership and acquisition steps and agricultural processing and cultivation steps are all incorporated into the first step. Similarly, the pathways end at the production of a final use energy commodity, they do not incorporate specific details on the various final steps associated with final transport from the point of production to the point of final delivery. These additional final steps could ultimately represent significant additional steps and infrastructural costs which will need to be considered in the context of the Hawaii Bioenergy Master Plan.

To facilitate robust consideration of the bioenergy pathways and value chain components relevant to this study, information gathered from the literature search on various feedstock, process steps, and final products were assembled logically into a set of representative pathways. Additional work was done to consistently group the process steps into distinct categories, and combine the like pathway to enable the illustration of the various interconnected steps associated with the multiple routes to arrive at final product end-points. Figure 3 provide information on the process steps that were included in the Additional information on the pathways can be found in the appropriately named section.

FIGURE 3: Process Steps in the Bioenergy Value Chain



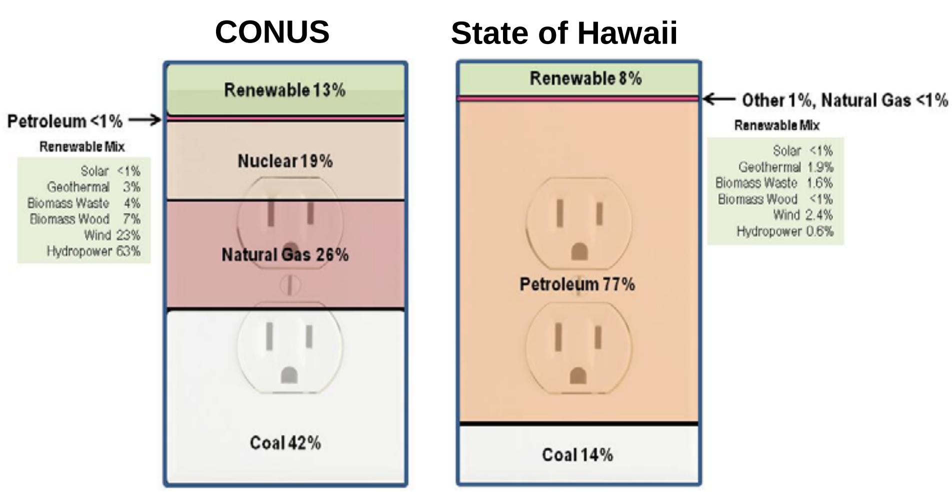
Consideration of Hawaii Conditions

Critical to the understanding of the opportunities associated with transitioning the existing energy economy to include increasing amounts of biomass-derived fuels, are the consideration of factors that are uniquely relevant to Hawaii conditions. This is a term is often used within the State to address the various factors that are typically outside the consideration of other locales.

The Hawaiian Islands' remote South Pacific location, strong reliance on fossil fuels, climate conditions and weather, population, tourism, topography, agronomy, and existing energy markets, all play strongly among the criteria that strongly factor into the consideration of whether a pathway is relevant to the Hawaiian conditions. From the perspective of climate, Hawaii offers some of the most ideal conditions for growing biomass resources, but there are also constraints in the form of land use, labor, and water issues that will likely overlap regarding biomass cultivation, but these constraints may also impact Hawaii's indigenous cultivation of food crops. Many of these issues are addressed in other documents compiled by the State of Hawaii Department of Economic Development and Tourism.

Equally or perhaps more important are the impacts that affect other aspects of the value chain. To be clear, climate, soil, and rainfall are relevant to Hawaii conditions, but they might not be more important than harbor constraints that could delay inter-island transfer of biomass feedstock to a biorefinery, or an imbalance on the product slate coming from the two Kapoleii petroleum refineries on Oahu. Since this is the first documented consideration of unique attributes that are relevant to Hawaii conditions, further dialog and stakeholder input may be a useful future exercise. Considering a comparison of the use of energy in the production of electricity, as illustrated in Figure 4, could reveal an interest in pursuing the production of electricity from biomass, whereas refinery constraints based on the product mix from the Hawaii based refineries, included in Figure 5, might influence the decision criteria from one targeted biomass type of other biomass conversion considerations. Additionally, other considerations could include an assessment of Hawaii's tourism industry, its role in the State economy, and its associated impact on energy use.

Figure 4: Comparison Electric Generation Utility Mix CONUS and Hawaii



Note: Includes utility-scale generation only. Excludes customer-sited generation, i.e., residential and commercial rooftop solar PV. Source: U.S. Energy Information Administration, Electric Power Monthly.
http://www.eia.gov/electricity/monthly/current_year/march2012.pdf

Figure 3: Comparison of Typical Barrel Fractions – Hawaii and CONUS refineries

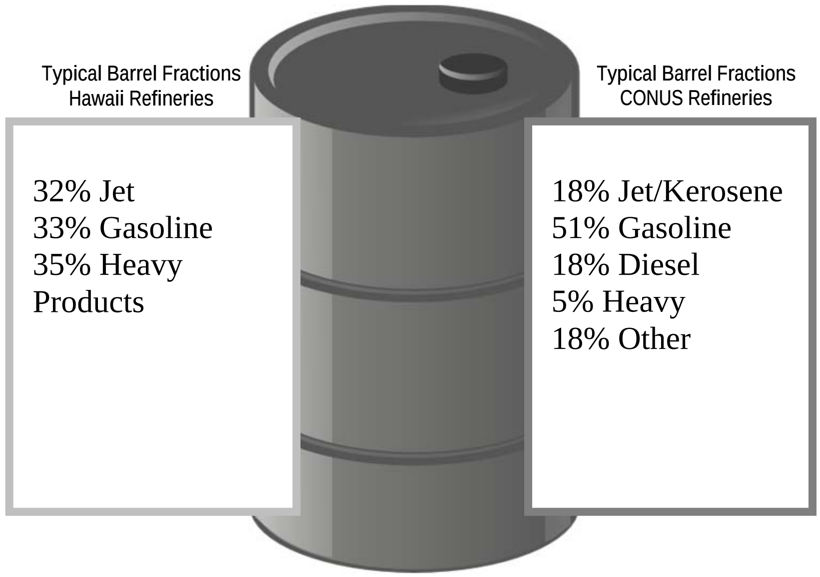
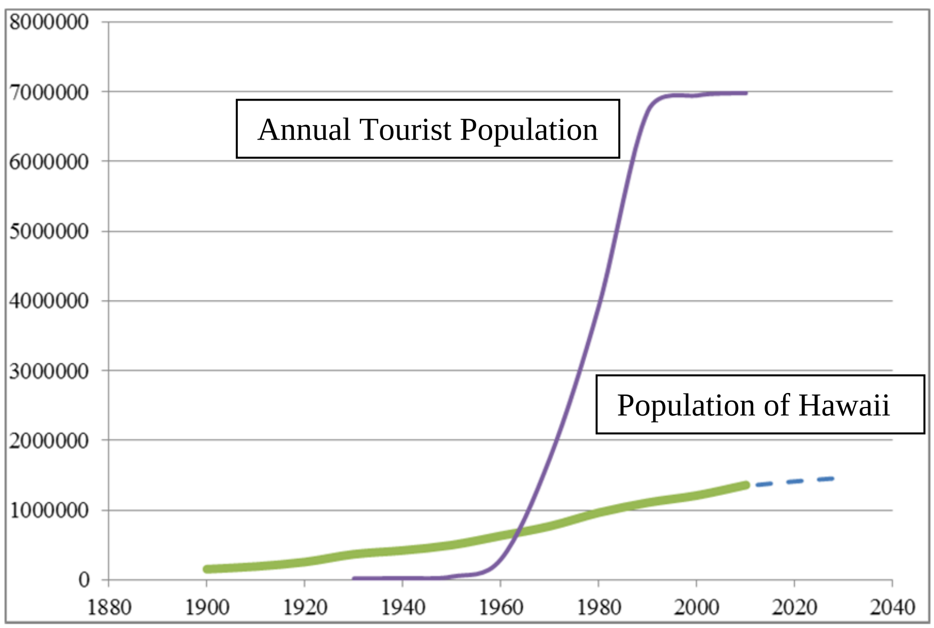


Figure 6: Consideration of Tourism on Fuel Requirements



To effectively consider these uniquely Hawaiian aspects in the consideration and evaluation the existing pathways, the concept of decision filtering was employed. In this manner, only those pathways and Life Cycle Analyses that are relevant to Hawaii will be considered.

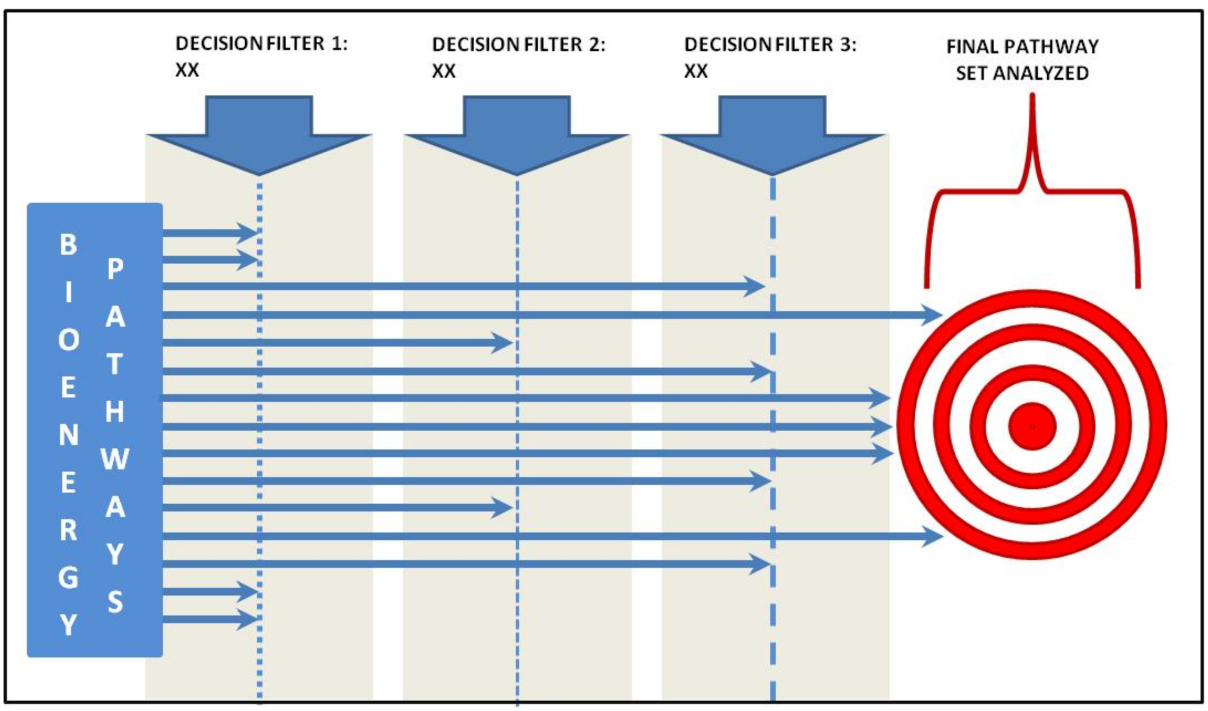
The use of decision filters enables the filtering of information in various options or data sets via a series of preset logic conditions. For the purposes of this report we considered the use of a three tiered decision filter that was intended to consider the following:

Filter 1. Cultivation Limit – Primary filter was intended to refine the pathways by limiting feedstock that is not appropriate for cultivation in Hawaii. This first level filter was intended to address pathways that were primarily inappropriate for consideration, for example pathways based on corn, which thrives in the Midwestern U.S. would not be appropriate as a large-scale biofuel purpose grown crop.

Filter 2. Scale Limit -- The second level filter was intended to refine the set of pathways to only those that were of an appropriate scale that made sense in Hawaii. Because of logistical constraints of inter-island transport, it was thought that smaller or distributed sized systems might make more sense than massive scale operations. Simply, larger plants with larger biofuel production capacities will require a larger amount of feedstock to remain operational.

Filter 3. Final Product Slate Limit -- The third and final filter was intended to consider the final product slates. For instances, if a number of final biofuel product slates were produced there are market limitations regarding the amount of product that can be absorbed into the marketplace. As such, this market filter could be used to focus production to only one final product such as biohydrogen or a percent blend amount such as 50% domestic ethanol supply.

Figure 7: Illustrative Example for Decision Filters Consideration of Pathways



Discussion of Pathways Analysis:

General Discussion --

As noted previously, pathway analysis is an established and rational means for considering and analyzing energy technology options and opportunities. Its use requires the development of a rigorous analytical framework to consider and estimate the energy pathway from their earliest beginning to their logical conclusion. In applying the pathway analysis methodology, it is possible to consider the various value chain components unique to the pathway or pathways under study and the range of cost and impacts at each step to generate detailed information that is representative of the pathways and comparable to other pathways and their incremental assessments. For instance, pathways based on existing technology and infrastructure (a conventional pathway) could be compared to various advanced technology pathways to illustrate how the costs and benefits compare. Or, it could be used to highlight cost and benefits that are external to traditional economic analysis, otherwise referred to as externalities.

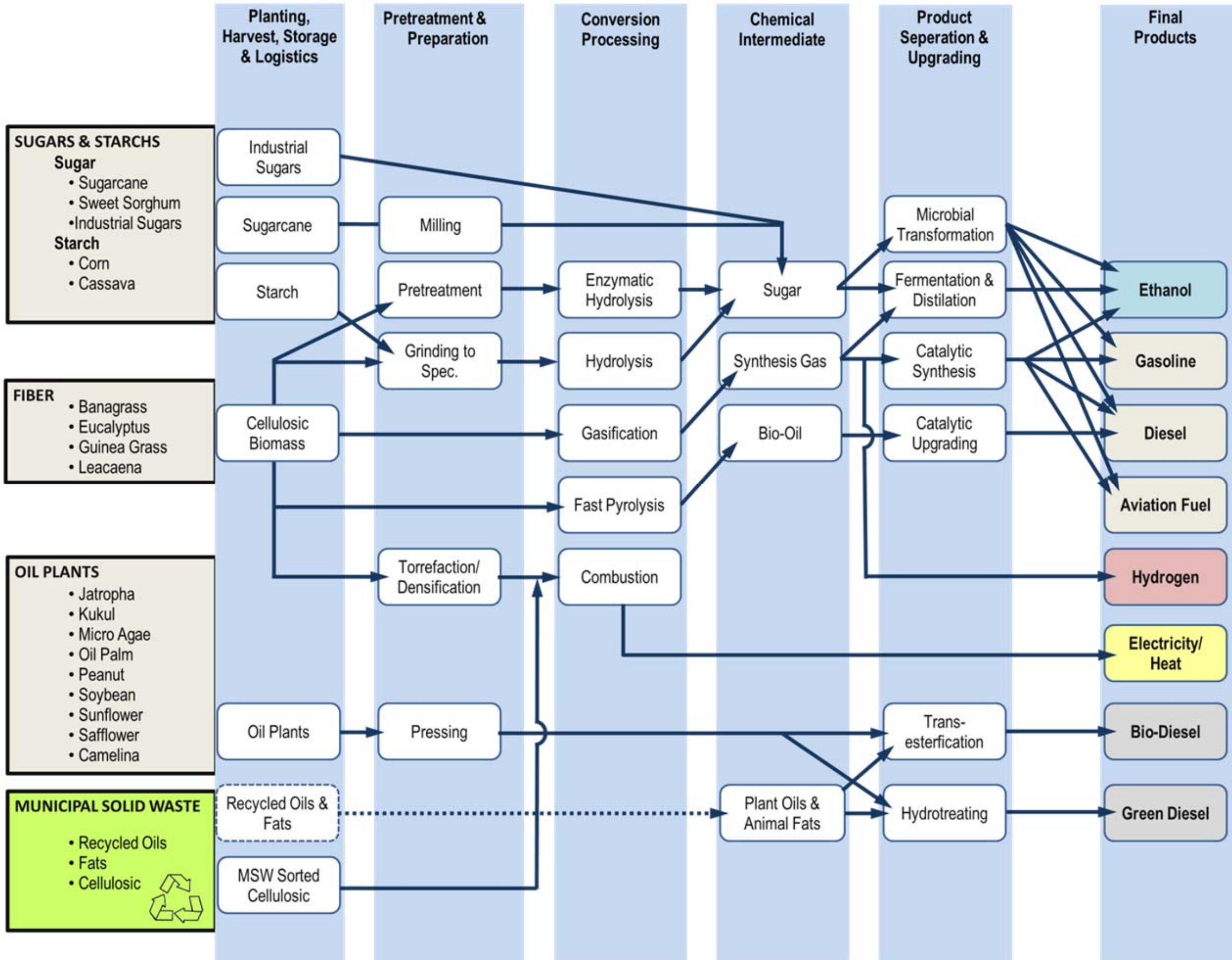
Pathways analysis results can be used in a number of ways. For instance in a report prepared in 2000 for the State of Hawaii titled, "Nurturing a Clean Energy Future in Hawaii: Assessing the Feasibility of the Large-Scale Utilization of Hydrogen and Fuel Cells in Hawaii" various hydrogen energy pathways were developed and analyzed to assess the feasibility of a long-term transition to a hydrogen-based energy economy. This report is less ambitious in some way because the State of Hawaii already has a long history in agribusiness and using bioenergy to meet a portion of its energy demand, whereas the development of a hydrogen economy involves consideration of the chicken and egg paradigm. In this case, pathway analysis is being used to compile a set of bioenergy pathways that are relevant to the Hawaii conditions, and gather available information on these pathways to further strategic discussions on the biofuel developments.

An energy economy, despite its regional location and associated attributes, has developed over a period of many years, and is typically very specialized to meet the energy demands of customers at the lowest cost, the business interests of its investors while achieving regular returns on investment, and the legal requirements of the regulatory bodies and local jurisdictions. Hawaii's geographic isolation (nearly 2400 miles to its nearest continental neighbor in North America) and natural composition as an 8 island archipelago, presents a number of energy supply and security concerns. For example, the State's current energy economy relies heavily on imported fossil fuels, importing nearly 94 percent of primary energy in 2010[4]. This reliance on imported energy puts the state in a vulnerable position with respect to energy security. And, for this reason the Hydrogen legislature has set aggressive targets the development of bioenergy capacity.

To achieve these development targets, this study considered the biomass feedstocks that can be successfully cultivated in, and in some cases around the State and the consideration of all the processes involved in delivering this energy to the point of utilization. In the case of the bioenergy pathways, these value chain components include: Feedstock Cultivation and Harvesting, Feedstock Logistics, Pretreatment and Preparation, Conversion Processing to Chemical Intermediates, Product Separation and Upgrading to Final Products. Figure 8 illustrates the representative pathways under consideration in this analysis.

[4] http://www.eia.gov/state/state-energy-profiles.cfm?sid=HI

FIGURE 8: Examples of Possible Bioenergy Pathways



Feedstock Cultivation and Harvesting

Feedstock cultivation and harvesting involves on-purpose production of crop products from which bio-based Sugar, Starch, Fiber, and Oil will be produced for use in downstream processes that could produce a range of bioenergy fuels ranging from gasoline and diesel blend stocks, to drop-in-type, biohydrocarbon transportation fuels meeting market specifications, synthesis gas and neat hydrogen, electricity and heat generation, as well as biodiesel and Green Diesel Products. In some, regional areas this may or may not include municipal solid waste streams or animal wastes.

Figure 8 illustrated example pathways, shows the feedstock cultivation and harvest activities in the first column. On the extreme left side of the graphic there are 4 boxes showing the bio-energy feedstocks that were researched and considered as part of this study. In some cases, these crops are established and available for immediate use, in other cases the feedstocks could be undergoing field trials in Hawaii. The 4th box on the left lists the municipal solid wastes and that could be used to produce bioenergy, and positively impact island waste management. The first three boxes are considered to be “primary feedstocks” because they are purpose grown for use as bioenergy production. “Secondary feedstocks” consist of various waste streams, including but not limited to: manure from farm animals, food residue, wood processing mill residue, and pulping liquors, municipal solid waste and sanitary waste sludge, landfill gases, urban wood waste , construction and demolition debris, and packaging waste.

As previously depicted, this critical first step in the process will consists of planting, harvesting or collecting the feedstock from the production area, processing it for use in a biomass facility, storing it to provide for a steady supply, and delivering it to the plant.

Potential environmental impacts could result from biomass feedstock production activities such as the collection of waste materials and growth and harvesting of woody and agricultural crops or algae, preprocessing, and transportation activities.

Pretreatment and Preparation

Biofuels produced from various lignocellulosic materials, such as wood, agricultural, or forest residues, have the potential to be a valuable substitute for, or complement to, gasoline. Many physicochemical structural and compositional factors hinder the hydrolysis of cellulose present in biomass to sugars and other organic compounds that can later be converted to fuels. The goal of pretreatment is to make the cellulose accessible to hydrolysis for conversion to fuels. Various pretreatment techniques change the physical and chemical structure of the lignocellulosic biomass and improve hydrolysis rates. During the past few years a large number of pretreatment methods have been developed, including alkali treatment, ammonia explosion, and others. Many methods have been shown to result in high sugar yields, above 90% of the theoretical yield for lignocellulosic biomasses such as woods, grasses, corn, and so on. In this review, we discuss the various pretreatment process methods and the recent literature that has reported on the use of these technologies for pretreatment of various lignocellulosic biomasses.

Conversion Processing to Chemical Intermediates

- **Thermal Processing --** The oldest and most common way is to burn biomass to create heat. This can be used directly for heating, cooking and industrial processes, or indirectly to generate electricity. At biomass power plants, biomass is burned in a boiler to produce high-pressure steam, which, in turn drives a turbine to generate electricity.

- **Thermochemical Processing --** By heating (but not burning) plant matter, it is possible to break down biomass into gases, liquids and solids, which can be further processed into gas and liquid fuels like methane and alcohol. Biomass reactors heat biomass in a low-oxygen environment to produce a fuel gas (mostly methane), which can then fuel steam generators, combustion turbines, combined cycle technologies or fuel cells.

- **Biochemical Processing --** Adding bacteria, yeasts and enzymes to biomass liquids causes biomass materials to ferment and change into alcohol. A similar process is used to turn agricultural products into ethanol (grain alcohol), which is then mixed with gasoline to make an ethanol-gasoline blend. And when bacteria are used to break down biomass, methane is produced and can be captured from landfills and sewage treatment plants to produce fuel for heat and power.

Product Separation and Upgrading to Final Products

One of the challenges that remain for biofuel production are technologies designed to separate, purify, and conduct final transformations as needed to convert biomass to biochemicals and biofuels. By some estimates, "separation" alone accounts for approximately 60 - 80% of the processing costs depending on whether these are fermentation and distillation processes for Ethanol, or Catalytic processes for upgrading drop-in fuels or Transesterfication or Hydrotreating technologies to complete Bio- and Green-Diesel fuel formulation. Advanced membrane technology offers opportunities to reduce energy consumption, minimum contamination risks, and other operation and maintenance costs.

Conclusions:

Information on transportation fuels was compared against data and information resulting from the U.S. Environmental Protection Agency (EPA) analysis on transportation fuel pathways developed in accordance with the most recent revisions to the Renewable Fuel Standard (RFS), commonly referred to as RFS2. The RFS2 data is significant because there are a number of eligible advanced transportation fuel pathways that have been identified and referenced in section § 80.1426 for the RFS2 regulations. Only these pathways are eligible for consideration as an advanced renewable fuel according to Federal regulations, and the only pathways that are eligible for the generation of Renewable Fuel Identification Numbers (RINs).

A RIN number is essentially a renewable fuel credit, and consists of a registered serial number assigned to each patch of renewable fuel as it is introduced into U.S. commerce. The generation and tracking of RIN credits is regulated by the U.S. EPA and in part used to track the Nation's progress toward renewable fuel targets established by the U.S. Congress. Any bioenergy-based transportation fuel that is not included in this subset of approved pathways will need to petition the EPA to qualify their production pathway under the RFS2. See Table 1, for specific information on eligible EPA advanced transportation fuel pathways and their relevance to Hawaii.

Information from GREET Models were also investigated. Figure 9 provides an illustration of 100 critical pathways that have been modeled. While these pathways are extensive and detailed only a very limited number of the pathways prepared by ANL in its pathways library and specifically prepared for the California Low Carbon Fuel Standard are relevant to the Hawaii conditions. While some elements of these analysis are relevant and can be used as a foundation for Hawaii specific pathways, it is imperative that independent analysis specific to Hawaii are undertaken.

FIGURE 9: GREET Model Fuel Pathways from Various Feedstocks

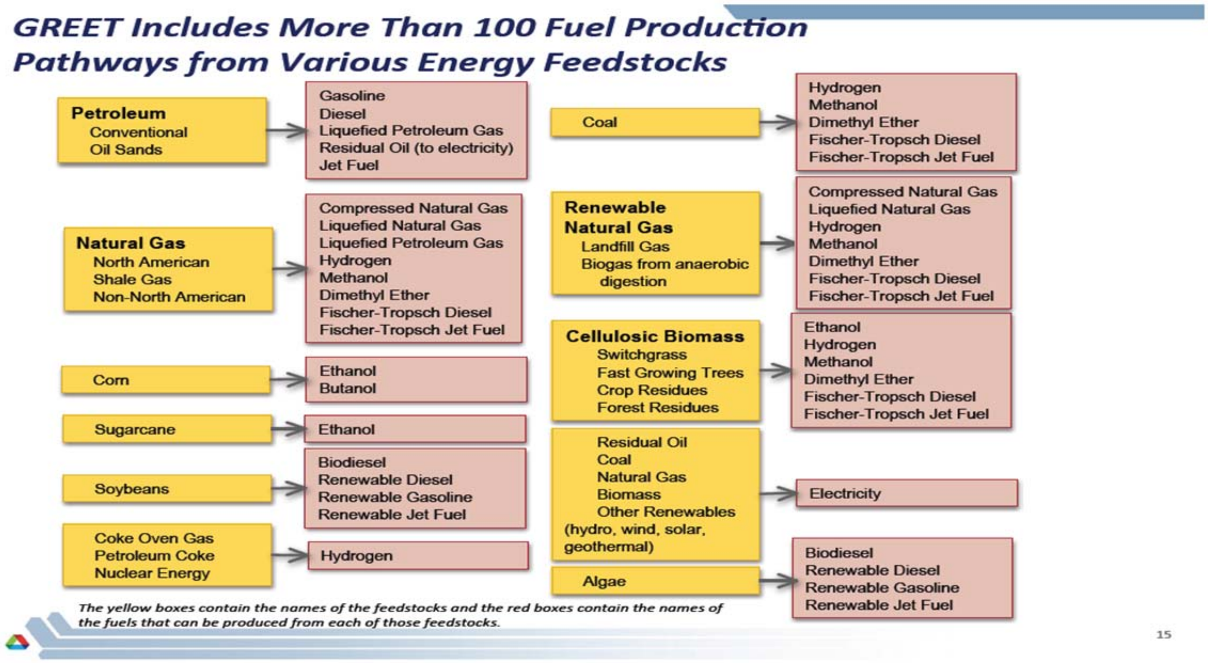


TABLE 1 TO § 80.1426—APPLICABLE FUEL PATHWAY FOR USE IN GENERATING RINS AND ASSOCIATED D-CODE DESIGNATIONS

Fuel type	Feedstock	Production process requirements	D-Code	Relevancy to Hawaii
A Ethanol	Corn starch	All of the following: Dry mill process, using natural gas, biomass, or biogas for process energy and at least two advanced technologies from Table 2 to this section.	6	NO FAILS FILTER 1 CORN FEEDSTOCK
B Ethanol	Corn starch	All of the following: Dry mill process, using natural gas, biomass, or biogas for process energy and at least one of the advanced technologies from Table 2 to this section plus drying no more than 65% of the distillers grains with solubles it markets annually.	6	NO FAILS FILTER 1 CORN FEEDSTOCK
C Ethanol	Corn starch	All of the following: Dry mill process, using natural gas, biomass, or biogas for process energy and drying no more than 50% of the distillers grains with solubles it markets annually.	6	NO FAILS FILTER 1 CORN FEEDSTOCK
D Ethanol	Corn starch	Wet mill process using biomass or biogas for process energy.	6	NO FAILS FILTER 1 CORN FEEDSTOCK
E Ethanol	Starches from crop residue and annual cover crops	Fermentation using natural gas, biomass, or biogas for process energy.	6	POTENTIALLY RELEVANT
F Biodiesel, renewable diesel, jet fuel and heating oil.	Soy bean oil; Oil from annual cover crops; Algal oil; Biogenic waste oils/fats/greases; Non-food grade corn oil; Camelina oil.	One of the following: Trans-Esterification, Esterification, Hydrotreating, Excluding processes that co-process renewable biomass and petroleum.	4	POTENTIALLY RELEVANT
G Biodiesel, heating oil	Canola/Rapeseed oil	Trans-Esterification using natural gas or biomass for process energy.	4	POTENTIALLY RELEVANT
H Biodiesel, renewable diesel, jet fuel and heating oil.	Soy bean oil; Oil from annual cover crops; Algal oil; Biogenic waste oils/fats/greases; Non-food grade corn oil Camelina oil.	One of the following: Trans-Esterification, Esterification Hydrotreating Includes only processes that co-process renewable biomass and petroleum.	5	POTENTIALLY RELEVANT
I Naphtha, LPG	Camelina oil	Hydrotreating	5	POTENTIALLY RELEVANT
J Ethanol	Sugarcane	Fermentation	5	RELEVANT
K Ethanol	Cellulosic Biomass from crop residue, slash, pre-commercial thinnings and tree residue, annual cover crops, switchgrass, miscanthus, napiergrass, giant reed and energy cane; cellulosic components of separated yard waste, food waste; and/or MSW.	Any	3	POTENTIALLY RELEVANT
L Cellulosic Diesel, jet fuel and heating oil.	Same as K	Any	7	POTENTIALLY RELEVANT

M Renewable Gasoline and Renewable Gasoline Blend Stock.	Same as K	Catalytic Pyrolysis, Gasification and Upgrading, Direct Fermentation, Fermentation and Upgrading, all utilizing natural gas, biogas, and/or biomass as the only process energy sources. Any process utilizing biogas and/or biomass as the only process energy sources.	3	POTENTIALLY RELEVANT
N Butanol	Corn starch	Fermentation; dry mill using natural gas, biomass, or biogas for process energy.	6	NO FAILS FILTER 1 CORN FEEDSTOCK
O Ethanol, renewable diesel, jet fuel, heating oil, and naphtha.	The non-cellulosic portions of separated food waste.	Any	5	POTENTIALLY RELEVANT
P Biogas	Landfills, sewage waste treatment plants, manure digesters.	Any	5	POTENTIALLY RELEVANT

Lifecycle Analysis Workgroup (LCA)
-- Investigation of the lifecycle of Energy Use and Greenhouse Gases of available transportation fue l pathways (so called Well-to-Wheel or WTW) including Sustainability, Land Use Conversion, Fuel Co-products, Default Values, Uncertainty, etc.)

	Pathway	Fuels Pathways	Publishing Date	File Location	Notes	Relevancy to Hawaii
1	CA LCFS-Modified GREET Pathway:	CARBOB (California Gasoline Blendstock)	27-Feb-09	http://www.arb.ca.gov/fuels/lcfs/022709lcfs_carbob.pdf		RELEVANT BASE CASE
2	CA LCFS-Modified GREET Pathway:	CaRFG (California Reformulated Gasoline)	27-Feb-09	http://www.arb.ca.gov/fuels/lcfs/022709lcfs_carfg.pdf		RELEVANT BASE CASE
3	CA LCFS-Modified GREET Pathway:	ULSD (California Ultra Low Sulfur Diesel)	27-Feb-09	http://www.arb.ca.gov/fuels/lcfs/022709lcfs_ulsd.pdf		RELEVANT BASE CASE
4	CA LCFS-Modified GREET Pathway:	Corn Ethanol	27-Feb-09	http://www.arb.ca.gov/fuels/lcfs/022709lcfs_cornetoh.pdf		NO FAILS FILTER 1 CORN FEEDSTOCK
5	CA LCFS-Modified GREET Pathway:	Sugarcane Ethanol (from Brazil)	20-Jul-09	http://www.arb.ca.gov/fuels/lcfs/092309lcfs_cane_etoh.pdf		RELEVANT PATHWAY
6	CA LCFS-Modified GREET Pathway:	Cellulosic Ethanol (from Farmed Trees)	27-Feb-09	http://www.arb.ca.gov/fuels/lcfs/022709lcfs_trees.pdf		RELEVANT PATHWAY
7	CA LCFS-Modified GREET Pathway:	Cellulosic Ethanol (from Forest Waste)	27-Feb-09	http://www.arb.ca.gov/fuels/lcfs/022709lcfs_forestw.pdf		RELEVANT PATHWAY

8	CA LCFS-Modified GREET Pathway:	**Biodiesel** (from Soybean)	14-Dec-09	http://www.arb.ca.gov/fuels/lcfs/121409lcfs_soybd.pdf		RELEVANT PATHWAY
9	CA LCFS-Modified GREET Pathway:	**Renewable Diesel** (from Soybean)	14-Dec-09	http://www.arb.ca.gov/fuels/lcfs/121409lcfs_soyrd.pdf		RELEVANT PATHWAY
10	CA LCFS-Modified GREET Pathway:	**Compressed Natural Gas** (CNG) from North American Natural Gas (NA NG)	27-Feb-09	http://www.arb.ca.gov/fuels/lcfs/022709lcfs_cng.pdf		NO FAILS FILTER 1 NG
11	CA LCFS-Modified GREET Pathway:	**CNG** (from Landfill Gas)	27-Feb-09	http://www.arb.ca.gov/fuels/lcfs/022709lcfs_lfg.pdf		RELEVANT PATHWAY
12	CA LCFS-Modified GREET Pathway:	**Electricity** (Average and Marginal California Mix)	27-Feb-09	http://www.arb.ca.gov/fuels/lcfs/022709lcfs_elec.pdf		RELEVANT PATHWAY to BASE CASE
13	CA LCFS-Modified GREET Pathway:	**Hydrogen** (Gaseous Hydrogen from NA NG)	27-Feb-09	http://www.arb.ca.gov/fuels/lcfs/022709lcfs_h2.pdf		NO FAILS FILTER 1 NG
14	CA LCFS-Modified GREET Pathway:	**Liquefied Natural Gas** (LNG) from NA NG and Remote NG	23-Sep-09	http://www.arb.ca.gov/fuels/lcfs/092309lcfs_lng.pdf		NO FAILS FILTER 1 NG
15	CA LCFS-Modified GREET Pathway:	**LNG** (from Landfill Gas)	23-Sep-09	http://www.arb.ca.gov/fuels/lcfs/092309lcfs_lfg_lng.pdf		RELEVANT PATHWAY to BASE CASE
16	CA LCFS-Modified GREET Pathway:	**LNG** (from Dairy Digester Biogas)	23-Sep-09	http://www.arb.ca.gov/fuels/lcfs/092309lcfs_lng.pdf		RELEVANT POSSIBLE PATHWAY
17	CA LCFS-Modified GREET Pathway:	**Biodiesel** (from Used Cooking Oil)	23-Sep-09	http://www.arb.ca.gov/fuels/lcfs/092309lcfs_uco_bd.pdf		RELEVANT POSSIBLE PATHWAY

18	CA LCFS-Modified GREET Pathway:	**Renewable Diesel** (from Tallow)	23-Sep-09	http://www.arb.ca.gov/fuels/lcfs/092309lcfs_tallow_rd.pdf		RELEVANT POSSIBLE PATHWAY
19	CA LCFS-Modified GREET Pathway:	**CNG** (from Dairy Digester Gas)	20-Jul-09	http://www.arb.ca.gov/fuels/lcfs/072009lcfs_biogas_cng.pdf		RELEVANT POSSIBLE PATHWAY
20	CA LCFS-Modified GREET Pathway:	**Biodiesel** (Northern American Canola to Biodiesel plants in U.S.)	14-Dec-10	http://www.arb.ca.gov/fuels/lcfs/2a2b/internal/121410lcfs-canola-bd-rpt.pdf		RELEVANT POSSIBLE PATHWAY
21	CA LCFS-Modified GREET Pathway:	**Biodiesel** (from Corn Oil from Dry Mill Ethanol Plant)	14-Dec-11	http://www.arb.ca.gov/fuels/lcfs/2a2b/internal/121410lcfs-cornoil-bd-rpt.pdf		RELEVANT POSSIBLE PATHWAY
22	CA LCFS-Modified GREET Pathway:	**Ethanol** (Sorghum from Midwest)	28-Dec-10	http://www.arb.ca.gov/fuels/lcfs/2a2b/internal/122810lcfs-sorghum-etoh.pdf		NO FAILS FILTER 1 CORN
23	CA LCFS-Modified GREET Pathway:	**Biomethane** (from High Solids Anaerobic Digestion (HSAD) of Organic Wastes)	28-Jun-12	http://www.arb.ca.gov/fuels/lcfs/2a2b/internal/hsad-rng-rpt-062812.pdf		RELEVANT POSSIBLE PATHWAY

#	CA LCFS Pathways	Fuel Pathways	Posted Date	Submitted Application Files (including LCA information) ** (may or may not be approved by the CA process)	Notes	Relevancy to Hawaii
1	CA LCFS Private Producer Pathway -- Archer Daniels Midland (ADM)	Ethanol (from Corn)	12/14/2010	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/adm-col-15day-022112.pdf	8 subpathways for Columbus, NE	NO FAILS FILTER 1 CORN
2	CA LCFS Private Producer Pathway -- POET	Ethanol (from Corn)	12/14/2010	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/poet-032712.pdf	13 subpathways for multiple plants	NO FAILS FILTER 1 CORN
3	CA LCFS Private Producer Pathway -- Trinidad Bulk Traders Limited (TBTL)	Brazilian Sugarcane Ethanol Dehydration	12/14/2010	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/tbtl-rpt-ncbi-121410.pdf	Trinidad and Tobago	RELEVANT PATHWAY; SOME LOCATION SPECIFIC CONSTRAINT
4	CA LCFS Private Producer Pathway -- Green Plains	Ethanol (from Corn)	12/14/2010	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/gp-lak-rpt-ncbi-121410.pdf	Lakota, NE	NO FAILS FILTER 1 CORN
5	CA LCFS Private Producer Pathway -- Green Plains	Ethanol (from Corn)	12/14/2010	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/gp-cct-rpt-ncbi-121410.pdf	Central City, NE	NO FAILS FILTER 1 CORN
6	CA LCFS Private Producer Pathway -- LouisDreyfus Commodities	Ethanol (from Corn)	12/14/2010	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/ld-nor-rpt-ncbi-121410.pdf	Norfolk, NE	NO FAILS FILTER 1 CORN
7	CA LCFS Private Producer Pathway -- Conestoga (Arkalon Ethanol LLC)	Ethanol (from Sorghum/Corn)	1/10/2011	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/con-ark-ncbi-011011.pdf	Liberal, KS	RELEVANT PATHWAY; SOME LOCATION SPECIFIC CONSTRAINT

8	CA LCFS Private Producer Pathway -- Conestoga (Bonanza BioEnergy, LLC)	Ethanol (from Sorghum/Corn)	1/10/2011	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/con-bon-ncbi-011011.pdf	Garden City, KS	RELEVANT PATHWAY; SOME LOCATION SPECIFIC CONSTRAINT
9	CA LCFS Private Producer Pathway -- Clean Energy	Liquefied Natural Gas	1/10/2011	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/cle-ehr-ncbi-011011.pdf	Ehrenberg, AZ	NO FAILS FILTER 1 NG
10	CA LCFS Private Producer Pathway -- US Energy Partners LLC (White Energy)	Sorghum/Wheat Slurry/Corn	1/12/2011	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/we-rus-ncbi-011211.pdf	Russell, KS	RELEVANT PATHWAY; SOME LOCATION SPECIFIC CONSTRAINT
11	CA LCFS Private Producer Pathway -- US Energy Partners LLC (White Energy)	Ethanol (from Sorghum/Corn)	1/12/2011	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/we-plv-ncbi-011211.pdf	Plainview, TX	RELEVANT PATHWAY; SOME LOCATION SPECIFIC CONSTRAINT
12	CA LCFS Private Producer Pathway -- US Energy Partners LLC (White Energy)	Ethanol (from Sorghum/Corn)	1/12/2011	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/we-hrf-ncbi-011211.pdf	Hereford, TX	RELEVANT PATHWAY; SOME LOCATION SPECIFIC CONSTRAINT
13	CA LCFS Private Producer Pathway -- Flint Hills Resources (former Hawkeye Renewables, LLC)	Ethanol (from Corn)	1/24/2011	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/fhr-iow-012411.pdf	Iowa Falls, IA	NO FAILS FILTER 1 CORN
14	CA LCFS Private Producer Pathway -- KAAPA Ethanol, LLC	Ethanol (from Corn)	1/24/2011	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/kap-min-ncbi-012411.pdf	Minden, NE	NO FAILS FILTER 1 CORN
15	CA LCFS Private Producer Pathway -- Green Plains	Ethanol (from Corn)	1/24/2011	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/gp-ord-ncbi-012411.pdf	Ord, NE	NO FAILS FILTER 1 CORN
16	CA LCFS Private Producer Pathway -- Green Plains	Ethanol (from Corn)	1/24/2011	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/gp-she-ncbi-012411.pdf	Shenandoah, IA	NO FAILS FILTER 1 CORN

17	CA LCFS Private Producer Pathway -- Parallel Products, Inc	Ethanol (from Waste Beverage products)	1/24/2011	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/ppr-rnc-ncbi-012411.pdf	Rancho Cucamonga, CA	RELEVANT PATHWAY; SOME LOCATION SPECIFIC CONSTRAINT
18	CA LCFS Private Producer Pathway -- LouisDreyfus Commodities	Ethanol (from Corn)	3/29/2011	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/ld-grj-ncbi-032911.pdf	Grand Junction, IA	NO FAILS FILTER 1 CORN
19	CA LCFS Private Producer Pathway -- Siouxland, LLC	Ethanol (from Corn)	3/29/2011	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/sxl-jks-ncbi-032911.pdf	Jackson, NE	NO FAILS FILTER 1 CORN
20	CA LCFS Private Producer Pathway -- Vitol (Gasohol El Salvador)	Dehydrated Ethanol (from Brazilian Sugarcane)	6/24/2011	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/vit-gas-062411.pdf	El Salvador	RELEVANT PATHWAY; SOME LOCATION SPECIFIC CONSTRAINT
21	CA LCFS Private Producer Pathway -- Jamaica Broilers Ethanol	Dehydrated Ethanol (from Brazilian Sugarcane)	6/24/2011	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/jbe-jmc-062411.pdf	Jamaica	RELEVANT PATHWAY; SOME LOCATION SPECIFIC CONSTRAINT
22	CA LCFS Private Producer Pathway -- American Renewable Fuel Suppliers Ltda. de C.V	Dehydrated Ethanol (from Brazilian Sugarcane)	6/24/2011	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/arfs-els-062411.pdf	El Salvador	RELEVANT PATHWAY; SOME LOCATION SPECIFIC CONSTRAINT
23	CA LCFS Private Producer Pathway – EthylChem	Dehydrated Ethanol (from Brazilian Sugarcane)	6/24/2011	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/etch-tri-062411.pdf	Trinidad and Tobago	RELEVANT PATHWAY; SOME LOCATION SPECIFIC CONSTRAINT
24	CA LCFS Private Producer Pathway -- Golden Grain Energy, LLC	Ethanol (from Corn)	6/24/2011	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/gdg-msn-062411.pdf	Mason City, IA	NO FAILS FILTER 1 CORN

25	CA LCFS Private Producer Pathway -- Aberdeen Energy LLC (Glacial Lakes Corn Processors)	Ethanol (from Corn)	6/24/2011	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/glk-abd-062411.pdf	Mina, SD	NO FAILS FILTER 1 CORN
26	CA LCFS Private Producer Pathway -- Glacial Lakes Energy LLC (Glacial Lakes Corn Processors)	Ethanol (from Corn)	6/24/2011	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/glk-glk-062411.pdf	Watertown, SD	NO FAILS FILTER 1 CORN
27	CA LCFS Private Producer Pathway -- Illinois River Energy	Ethanol (from Corn)	1/6/2012	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/ire-121511.pdf	Rochelle, IL	NO FAILS FILTER 1 CORN
28	CA LCFS Private Producer Pathway -- Advanced BioEnergy	Ethanol (from Corn)	1/6/2012	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/abe-abd-121511.pdf	Aberdeen, SD	NO FAILS FILTER 1 CORN
29	CA LCFS Private Producer Pathway -- Advanced BioEnergy	Ethanol (from Corn)	1/6/2012	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/abe-fmt-121511.pdf	Fairmont, NE	NO FAILS FILTER 1 CORN
30	CA LCFS Private Producer Pathway -- National Biodiesel Board	BioDiesel (from Tallow)	1/6/2012	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/nbb-121511.pdf		RELEVANT PATHWAY; SOME LOCATION SPECIFIC CONSTRAINT
31	CA LCFS Private Producer Pathway -- R-Power	BioDiesel (from Tallow)	1/6/2012	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/rpw-121511.pdf	Redwood City, CA	RELEVANT PATHWAY; SOME LOCATION SPECIFIC CONSTRAINT
32	CA LCFS Private Producer Pathway -- Indonesian Sugar Group	Ethanol (from Sugar Molasses)	1/6/2012	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/indo-mol-121511.pdf	Indonesia	RELEVANT PATHWAY; SOME LOCATION SPECIFIC CONSTRAINT
33	CA LCFS Private Producer Pathway -- Siouxland Energy & Livestock Co-op	Ethanol (from Corn)	1/6/2012	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/sxl-121511.pdf	Sioux Center, IA	NO FAILS FILTER 1 CORN
34	CA LCFS Private Producer Pathway -- E Energy Adams LLC	Ethanol (from Corn)	1/6/2012	http://www.arb.ca.gov/fuels/lcfs/2a2b/apps/eea-122911.pdf	Adams, NE	NO FAILS FILTER 1 CORN
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