Hawai'i DBEDT

The Potential for Biofuels Production in Hawai'i

FINAL REPORT
B&V Project Number 147375

January 2010

Black & Veatch Corporation
11401 Lamar
Overland Park, Kansas 66211
Tel: (913) 458-2000 www.bv.com

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Principal Investigators:

Black & Veatch:
Jim Easterly, Project Manager
Keith Cummer
Nate Emsick
Matt Hunsaker
Bret Harper
Scot Olson
Bill Roush

University of Hawai'i*
Richard Ogoshi
John Yanagida

*University of Hawaii staff conducted the energy crop evaluation for this study, including identification of energy crop species, evaluation of available acreage, growing conditions, yields, and production cost estimates for Hawaii.

Table of Contents

List of Tables

List of Figures

1.0 Executive Summary

State of Hawai'i Act 240 (2006) emphasizes energy self-sufficiency by declaring the State's objective of having 20% of its transportation fuels from renewable sources by 2020. Act 240 created an alternative fuel standard (AFS) with intermediate goals of providing 10% of transportation fuels from renewable sources by 2010 and 15% by 2015. Black & Veatch, with the University of Hawaii as a subcontractor, were retained by the State of Hawai'i Department of Business, Economic Development, and Tourism (DBEDT) Strategic Industries Division to prepare a statewide multi-fuel biofuels production assessment that will help in determining how the State could potentially meet the alternative fuel goals in Act 240. This assessment addresses the potential feedstocks, technologies, and economics of biofuels production utilizing Hawai'i resources.

1.1 Biofuels

A significant amount of effort is underway to evaluate and commercialize new feedstocks and conversion technologies for the production of biofuels. Ethanol and biodiesel are two forms of biofuel that are the furthest along in establishing commercial viability. In addition to ethanol and biodiesel, options for producing other liquid fuels from biomass are also under development. These fuels include products that more closely resemble petroleum based fuels, such as gasoline, conventional diesel, and jet fuel.

Gaseous fuels, such as methane and hydrogen, can also be produced from biomass through biological or thermal processes. However, there are clearly major challenges associated with creating entirely new fuel storage, distribution and utilization systems for gaseous fuels if they are to be used for transportation fuel. Due in large part to these challenges, recent and ongoing efforts to develop transportation fuels from biomass have focused much more on the production of liquid fuels as the end product, rather than gaseous fuels such as hydrogen.

Finally, with the emergence of new options such as plug-in hybrid electric vehicles, electricity produced from biomass and other renewable resources could also be used to offset petroleum-based transportation fuel consumption. Unlike gaseous fuels, the infrastructure for electricity distribution is generally well established in Hawai'i. This could help lower barriers to using this form of energy for transportation. However, the need for a new fleet of vehicles capable of using electricity is still a major hurdle for this mode of transportation. Since the market value of electricity is generally high in Hawai'i, the development of integrated biomass conversion facilities that co-produce biofuel and electricity (for sale to the electric grid) could be economically attractive, depending on project-specific analyses in determining the greatest value for biomass feedstock use. It is quite possible that the integrated production of biofuels and electricity will often be attractive for project developers.

1.2 Technologies for Biofuel Conversion

There are a variety of conversion technologies that could play a role in Hawaii's developing bioeconomy. Each technology has certain benefits and constraints, particularly in relation to the type(s) of biomass feedstocks that are expected to be viable in Hawai'i over the coming years, and the optimum scale for conversion technologies in relation to the quantities of biomass that could be available. The development of biofuel production technology is currently in an intensive, rapidly evolving mode, and the marketplace will be sorting out the technologies that are the most competitive in particular circumstances. For this report, Hawaii's biofuel production potential was quantified by first estimating the tons of biomass feedstock that could be available in the future in the form of residues from agricultural, forestry, and urban activities, along with estimates of the amount of biomass that could be supplied from energy crops grown on various classifications of agricultural land. The corresponding amounts of biofuel that could be produced from these feedstocks were then calculated for various conversion technologies.

Since the scope of work defined at the outset of the project was to focus primarily on ethanol and biodiesel potential, these fuels were addressed in a base-case quantification of biofuels potential. Other emerging advanced biofuel production technologies and pathways were also evaluated in the study. The estimates regarding biomass feedstock availability and biofuel potential for the base-case examples should be valuable reference information that can be useful in understanding and evaluating the potential for various emerging biofuel conversion technologies, such as biomass-derived "green" gasoline, "green" diesel, or "green" jet fuel. For example, the information presented for characterizing biomass feedstock availability (which includes factors such as available acreage, locations, microclimates, and agricultural classification) is useful for understanding and evaluating feedstock supply availability for a wide range of biofuel conversion pathways. The estimates made for ethanol fuel potential in energy units (e.g., Btu's) can be viewed in general terms as a useful gage regarding the amount of other forms of liquid fuel that could be produced from biomass (such as gasoline, diesel, or jet fuel).

There are significant opportunities for R&D to improve the attractiveness of bioenergy production in Hawai'i over the next few years. Potential improvements include optimizing conversion systems designs (or selection) based on economy-of-scale factors, optimizing co-product strategies, development of new crop alternatives (including crop varieties selected or tailored to specific micro-climate conditions in Hawai'i), and improvements in the yields from existing crops (such as sugarcane).

1.2.1 Commercial and Near Term Commercial Technologies

Biofuel conversion technologies are selected to convert available biomass resources as efficiently as possible. Three different biomass feedstock categories were identified for this project: 1) sugars; 2) fats, oils, and greases (FOG); and 3) fibers. Sugar feedstocks can be readily fermented to produce ethanol. FOG can be converted into biodiesel through transesterification. Biodiesel is similar to conventional diesel, but contains about 8.5% less energy per gallon. Cellulose fibers, which include biomass material such as wood, tall grasses, and crop residues, can be converted into biofuel through biochemical conversion pathways (such as enzymatic hydrolysis and fermentation) or through thermal conversion, where intermediate gases or liquid products are reformed to useable liquid fuels. Table 1-1 lists feedstock types and conversion pathways that were used to arrive at base-case biofuel production estimates in this report.

Table 1-1. Commercial and Near Term Biomass Conversion Technology Summary.

Feedstock Type	Conversion Pathway	Product	Commercialization Status
Sugar			
Sugarcane	Conventional Fermentation	Ethanol	Commercial
Molasses			
Sweet Sorghum*			
Fiber			
Banagrass	Enzymatic Hydrolysis and Fermentation or Thermochemical Conversion	Ethanol	Near Commercial; Demonstration Phase
Eucalyptus			
Leucaena			
Cellulosic wastes			
Oil			
Oil Palm	Transesterification	Biodiesel	Commercial
Jatropha			
Waste Oil			

Notes:
* Due to lack of available data, sweet sorghum production potential was not investigated for this effort.

1.2.2 Emerging Biofuel Conversion Technologies

A variety of new processing technologies are being developed that could produce green gasoline, green diesel, or green jet fuel from sugar-based or cellulosic-based biomass feedstocks. In each of these cases the green biofuel will be equivalent to, or superior to, the corresponding petroleum-derived fuel on an energy per gallon basis, and on the basis of other fuel properties.

Biological conversion technology is being developed that could convert sugar from crops such as sugarcane or sweet sorghum, into various chemicals and renewable fuels. For example, a Brazilian-based company, Amyris (and its U.S. subsidiary Amyris Fuels, LLC) is developing conversion technology that will use modified microorganisms to convert sugar into diesel, jet fuel, gasoline, and/or a variety of other products, such as lubricants or chemicals. Hawaii BioEnergy LLC is evaluating, and is optimistic about, the potential to use Amyris technology in Hawaii to produce conventional hydrocarbon-based fuels from sugar crops.

Pyrolysis is a developing technology that may prove to be a good match with the quantities of biomass available in Hawai'i and their geographic dispersion across the State. With pyrolysis, cellulosic biomass is heated in the absence of oxygen to create bio-oil, a mixture of hydrocarbons which resembles a low quality petroleum-based crude oil. Numerous small to medium-scale pyrolysis systems could be used to produce an intermediate bio-oil that can then be transported (via truck within an island, or via barge or ship between islands) to a large centralized refining facility. Companies such as Ensyn and Dynamotive have commercial pyrolysis systems that could be used in this type of application. Further refining may then be able to convert the bio-oil into more readily useable fuels, such as green gasoline, green diesel, and/or green jet fuel. One Hawaiian petroleum refiner, Tesoro, is collaborating with a team of technology developers to begin exploring the potential for refining biomass-derived pyrolysis oil into conventional fuels in their refinery.

The Fischer-Tropsch (F-T) process, which is the conversion of biomass through gasification and catalytic reformation of the biomass-derived syngas, offers the potential to create a variety of different products including diesel fuel, gasoline, and jet fuel. Based on current commercialization efforts, it appears that these F-T systems may need to process 1,000 to 2,000 tons per day of biomass to be economically attractive. This could be a drawback for development of these systems in Hawai'i, where geography imposes limitations on resource availability and transportation. A commercial-scale demonstration of this technology developed by CHOREN Industries will process about 235 tons/day of biomass to produce green diesel fuel at a facility in Germany; it will provide useful information for smaller-scale Fischer-Tropsch-based systems that could potentially be developed in Hawaii.

The use of microorganisms that can ferment syngas into ethanol may offer one alternative approach to using catalysts for converting biomass-derived syngas to liquid fuel It is possible that conversion units based on this syngas fermentation technology can be commercially viable at a smaller scale than catalytic/Fischer-Tropsch systems for converting syngas to liquid fuel – this could make the microorganism fermentation option a good fit for the scale of biomass availability and system sizes suitable for Hawaii. Companies such as Coskata, INEOS, and LanzaTech are developing these types of conversion systems.

Emerging approaches are being developed that can convert FOG feedstocks to "green" diesel via hydroprocessing or to jet fuels via deoxygenation and selective cracking/isomerization. Since fats and greases are in limited supply in Hawai'i, the main potential for FOG feedstocks would be plant oils. In our study of oil crop alternatives and costs for Hawai'i, it was found that producing plant oil is distinctly more expensive than producing cellulosic biomass. Vegetable oil from algae production offers significant promise for producing large amounts of oil per acre of land; however, substantial development efforts will be needed before the true viability of algal oil can be proven.

The status of emerging biofuel technologies are discussed in greater detail in Section 3.

1.2.3 Economies of Scale

Large biofuel production facilities are generally expected to experience economy-of-scale benefits that will enable production of liquid fuel at a lower cost per gallon than smaller facilities. This issue is of particular importance in Hawai'i where geography imposes constraints on resource availability and transport of solid biomass feedstocks. These constraints were taken into consideration in developing cost estimates for biofuels production in Hawai'i. Detailed cost estimates for cellulosic ethanol production recently updated by the National Renewable Energy Laboratory (NREL) showed cellulosic ethanol conversion costs in the range of $0.92 per gallon (on a levelized basis) by the year 2012 for large biochemical-based conversion facilities designed to process 2,200 tons per day of biomass feedstock (NREL, 2009). By comparison, in our base case analysis for Hawai'i, a conversion cost estimate of $1.36 per gallon was used. This estimate adjusts for economy-of-scale issues with the expectation that in Hawai'i, 500 to 800 tons per day may be a more likely scale for facilities based on acreage and transport constraints. This potential economy-of-scale drawback for biofuel production in Hawaii can be offset by the advantage that Hawaii facilities will have in marketing electricity co-produced with biofuel for distinctly higher electricity prices than "mainland" facilities.

As noted earlier, technologies such as pyrolysis may offer solutions to the issues of resource distribution and economies of scale related to biomass processing. Several medium-scale (100 to 700 ton per day) pyrolysis facilities may be useful in converting biomass into pyrolysis oil for processing at a centralized facility to produce transportation fuels. It is likely that pyrolysis oil can be stored and transported with greater ease and at lower cost than solid biomass feedstocks. The technology used in converting raw biomass to pyrolysis oil is fairly straightforward and is generally well suited to small- to medium-scale applications.

Although most conversion technologies options are likely to benefit from economy-of-scale factors, not all will necessarily be affected to the same degree. For example, the cost of transesterfication technologies used for producing biodiesel from vegetable oils are generally not impacted as much by economy-of-scale issues as conversion processes for producing ethanol from cellulosic biomass, such as biochemical (e.g., enzymatic hydrolysis) or thermochemical (e.g. gasification) processes.

1.3 Biofuel Potential from Hawai'i Resources

There are two general categories of possible biomass resources that can be used for biofuel production in Hawai'i: biomass residues and dedicated energy crops grown specifically for fuel and energy production. The potential for these sources are summarized below.

1.3.1 Potential from Biomass Residues in Hawai'i

Biomass residues encompass a wide variety of organic matter including agricultural, forestry, and municipal waste. The waste streams evaluated in this effort for their biofuel production potential include municipal solid waste, sewage sludge, FOG, bagasse fiber, cane trash, molasses, pineapple processing waste, macadamia nut shells, animal manures, and landfill gas. Table 1-2 shows biofuel production potential from these wastes streams. Many of the identified waste streams are currently used for processes other than biofuel production, so the economic and societal values of competing uses will be important in determining the extent to which some of these resources will be viable as feedstocks for biofuel production. The potential for ethanol production from wastes shown in Table 1-2 is based on the use of net biomass residues available, after current uses are subtracted from the total amount of waste currently produced.

Table 1-2. Total Hawai'i Biofuel Potential from Waste.

Fuel	Feedstock	Total Hawai'i Potential
Ethanol	Cellulosic wastes	90 million gallons/yr
Ethanol	Molasses	5 million gallons/yr
Biodiesel	Waste oil	2.0 – 2.5 million gallons/yr
Methane	Landfill gas	290 million scf/yr

A conversion process known as steam reformation could be used to convert the methane in landfill gas into 950 million scf/yr of hydrogen. While there are other theoretical paths for hydrogen production from biomass, none are expected to be commercial transportation options to impact Hawai'i within the next two decades.

1.3.2 Potential from Dedicated Energy Crops in Hawai'i

The potential amount of crops that could be grown for biofuels production throughout the state of Hawai'i was evaluated, including the estimated cost of producing these crops. There are substantial variations in temperature and precipitation across the Hawaiian Islands that will have significant bearing on the types of energy crops that can be successfully grown and the annual quantities of biomass that can be produced on specific island locations. To evaluate the prime irrigated and non-prime rainfed options, soil classifications were considered based on typical ambient temperatures and average moisture conditions. This approach was also helpful in identifying the most appropriate or promising pairings of different land types with different crops.

There are also significant variations in the suitability of soils for crop production, as well as substantial variations in land slope that will impact the ability to grow and harvest energy crops. To address these variations in microclimate, soil conditions, and land slope, geographic information system (GIS) software was used to evaluate energy crop suitability and energy crop productivity on land zoned for agriculture. The crop production potential for rainfed non-prime agricultural land, and irrigated prime agricultural land was quantified on each island.

There are a variety of potential herbaceous and woody plant species that could be attractive as energy crops in Hawaii, which can be selected for suitability to the varied microclimate and soil conditions found across the State's islands. Some crops are well known and substantial amounts of information and experience in growing these crops in Hawaii is available. In other instances, crops with significant promise have been identified and efforts to evaluate and field test productivity with the crops are underway. The three crop categories considered for biofuel production are sugar, fiber, and oil crops. Within these three categories, the six potential energy crops evaluated in detail in this report are summarized in Table 1-3.

Table 1-3. Energy Crops Selected Evaluated for Hawai'i.

Sugar Crop	Oil Crops	Fiber Crops
Sugarcane	Jatropha	Banagrass
	Oil Palm	Eucalyptus
		Leucaena

Analysis performed by the University of Hawai'i found that fiber crops showed the best potential for maximizing the tons of biomass that could potentially be produced in Hawai'i. For example, an herbaceous crop such as banagrass could be grown on warmer land (at lower elevations), and a woody crop such as Eucalyptus could be grown on somewhat cooler land (at higher elevations). Table 1-4 shows the maximum theoretical amount of biomass energy production potential in Hawai'i if all identified lands were used for the production of these two crops. The estimates shown in Table 1-4 are based on the use of enzymatic hydrolysis as the conversion technology, which would produce ethanol, as well as electricity as a co-product (where each ton of biomass is estimated to produce 80 gallons of ethanol per dry ton of biomass feedstock, plus 2.55 kilowatt hours of electricity, for each dry ton of fiber processed; these yield are expected to be achievable in the next four to six years).

Table 1-4. Energy Crop Potential and Biofuel Yield.

(thousand dry tons/yr)	Hawai'i	Maui	Molokai	Kauai	Oahu	Lanai	Total
Rainfed Land Potential							
Banagrass	1,610	606	264	258	211	66	3,015
Eucalyptus	2,493	53	6	0	0	0	2,552
Irrigated Land Potential							
Banagrass	1,378	2,446	455	1,832	1,978	502	8,589
Eucalyptus	718	47	6	3	45	53	873
Total Biomass	6,199	3,151	731	2,093	2,234	621	13,349
Energy Potential							
Ethanol* (million gal/yr)	**496**	**252**	**58**	**167**	**179**	**49**	**1,202**
Co-Generation** (MW)	**126**	**64**	**15**	**43**	**46**	**13**	**306**

Notes:
* Assumes conversion factor of 80 gallons of ethanol per dry ton of biomass
** Assumes co-generation potential of 2.55 kWh/gal of ethanol

The strength of the banagrass option is driven by somewhat aggressive projections regarding the potential yields for this crop. This also helps to lower the projected cost per ton of crop produced, improving the economics for making biofuel from this Banagrass. It is important to note that whether or not these Banagrass yields are achieved, crops such as sugarcane and Leucaena are still quite worthy of consideration in Hawai'i. The production of sugarcane is obviously a well established and understood crop option in Hawai'i, thus the case can be made that this option has lower risks. Conventional and/or advanced conversion options could convert the sugar and fiber residues into co-products of biofuel and electricity. Leucaena trees achieve relatively high yields of fiber per year, while also providing the added benefit of fixing nitrogen in the soil via the tree roots. The nitrogen fixing characteristic could allow for innovative potential options for crop production, such as inter-cropping of alternative fiber, feed, and/or food crops between rows of Leucaena trees (known as alley cropping).

There are also many emerging crop options that are worthy of research and development attention, which could be quite attractive in Hawai'i. For example, crops such as sweet sorghum are seen by organizations such as Hawaii BioEnergy LLC as having very strong potential as energy crops. It may be possible to have as many as three crop harvests per year in Hawaii with sweet sorghum. Since the plant readily produces seeds for propagation, efforts to improve yields through plant selection techniques should be able to progress rapidly. Similar to sugarcane, conventional conversion options (or conventional, combined with advanced conversion options), could be used to convert the sugar and as well as the fiber from sweet sorghum into co-products of biofuel and electricity.

The survey of land potentially available for energy crop production in Hawai'i concluded that there are approximately 810,000 acres of nonprime land and 300,000 acres of prime irrigated land within the state. It is believed that there would be less competition for nonprime lands, making them more accessible for energy crop production. However, irrigated lands offer significantly greater yields. Even though this study identified significantly more non-prime land than prime land, the higher yields achieved on prime irrigated lands lead to higher overall biomass production potential from these lands than from unirrigated non-prime lands.

1.4 Emerging Options for Biofuel Production

In addition to new biomass conversion methods, new crops and agricultural approaches will likely lead to increased yields and may offer opportunities for farmers to maximize their revenues with both energy and non-energy markets for their crops.

1.4.1 New Biomass Sources

Of the emerging biofuel options, production of biofuels from microalgae is a particularly interesting alternative. A primary advantage of algae is its potential for achieving very high yields per acre. It is theorized that some strains could yield as much as 6,000 to 15,000 gallons per acre of usable plant oil, which is much greater than the most productive land-based oil-seed crops. A substantial amount of research and development is needed if these types of algal oil yields are to be achieved; however, Hawai'i has the potential to become a center of microalgae research and development. Several organizations are currently involved with research and development operations in the state.

It is anticipated that algae would be grown in ponds. Land availability for thousands of acres of ponds in Hawai'i would clearly present some unique challenges in comparison to conventional crop production. Algae offers some key advantages, including the ability to grow in brackish water (such as ocean water, instead of fresh water), the ability to use/remove carbon dioxide from power plant stack gases (using the CO_2 for photosynthesis), and the ability to be produced on non-agricultural land.

Sweet sorghum and energy cane are other examples of herbaceous crops that may prove to have significant potential in Hawai'i. However, since yield data for these crops is still being developed, the economics of these crops were not modeled in our study. As noted earlier, sweet sorghum can produce both fermentable sugars as well as fiber. Energy cane is a variation of sugar cane which produces less sugar but more cellulosic biomass. New varieties of energy cane could be developed that maximize biofuel production potential per acre of cane grown in Hawai'i.

1.4.2 Options for Improving Biofuel Economics

In addition to new crops, new processing and agricultural methods may have the potential to improve the economics of crop and biofuel production. Integrated biorefineries may be able to produce multiple co-products, including chemicals, animal feed, fertilizer, pharmaceuticals, and/or food, in addition to energy in the form of liquid fuels, electricity, or thermal energy. The mix of higher value products produced in the biorefinery could reduce the cost of biofuel production. With respect to crop production, new approaches such as alley cropping may be able to improve the profitability of agricultural land, and help alleviate concerns over removing land from food production, offering the potential for integrated food and fuel production.

1.5 Results and Discussion

The following sections outline the total biofuel production potential of the state relative to demand and the impact that pursuing a major biofuel expansion strategy would have on land use. Recommendation and conclusions are also provided.

1.5.1 Current Fuel Consumption and Biofuel Demand

It is important to examine biofuel production potential in the context of current fuel usage in Hawai'i. Table 1-5 displays 2007 consumption levels of petroleum based fuels.

Table 1-5. Hawai'i Fuel Consumption, 2007.

Fuel	Million Gallons/yr
Gasoline	475
Diesel (on & off road vehicles, including farms)	66
Total Distillate Fuel (including diesel for vehicles)	391
Jet Fuel	449
Total Petroleum	2,222

Source: Energy Information Administration, U.S. DOE, 2007 (State Energy Profiles)

If ethanol is used as a 10 percent blend in all gasoline sold in the state, the total demand for ethanol in Hawai'i would be about 72 million gallons per year (adjusting for equivalent gallons of gasoline, since ethanol has about two-thirds as much energy per gallon as gasoline). Replacing 15 percent of the State's gasoline demand, which is the State's goal for 2015, corresponds to 107 million gallons per year of ethanol, based on gallons of gasoline equivalence; with the simplifying assumption that future demand stays similar to current levels with advances in vehicle fuel efficiencies. Replacing 20 percent of the State's gasoline consumption would require 143 million gallons per year of ethanol on a gallon of gasoline-equivalence basis, which corresponds to the State's renewable fuel goal for the year 2020. Achieving the replacement of 15 to 20 percent of gasoline consumption in Hawaii with ethanol would be facilitated if a portion of the vehicle fleet includes flexible fuel vehicles that can use gasoline/ethanol blends with up to 85 percent ethanol (E85). Alternatively, if biofuel in the form of "green" gasoline is produced, then the 20 percent gasoline displacement target would not require flexible fuel vehicles (and E85 fueling stations), and the 20 percent biofuel target would be about 95 million gallons of green gasoline consumption.

1.5.2 Biofuel Production Potential

Table 1-6 shows the estimated maximum biofuel potential from waste residues and dedicated energy crops in Hawaii. Since the anticipated yields of ethanol from biomass feedstocks are fairly well known, the maximum amount of ethanol that could be produced was estimated, in terms of gallons and Btu's of this biofuel. For advanced biofuel technologies that produce green gasoline, green diesel and green jet fuel, the anticipated gallons of fuel that will be produced per ton of biomass feedstock are still being refined. In order to estimate the amount of these fuels that could be produced, a useful approach is to assume that the efficiency of converting Btu's of feedstock into Btu's of liquid fuel will be somewhat similar for the different biofuel conversion pathways. This approach was used to provide the estimates shown in the table below, adjusting for the higher Btu content of gasoline, diesel, and jet fuels relative to ethanol.

Table 1-6. Maximum Theoretical Hawai'i Biofuel Production Potential.

Feedstock	**Biofuel** 10^{12} Btus/yr	**Ethanol** million gal/yr	**Green Gasoline** equivalent million gal/yr	**Green Diesel** equivalent million gal/yr	**Green Jet Fuel** equivalent million gal/yr
Energy Crops	101	1,202	786	722	751
Cellulosic Wastes	8	95	62	57	59
Total:	109	1,297	848	779	810

The production levels shown in Table 1-6 assume utilization of all identified agricultural land and unused biomass wastes/residues. Table 1-6 does not include yet-to-be-determined production of feedstocks such as algae, which could be produced on land that is not agriculturally zoned. Since there are many competing uses for agricultural land, these production levels are meant to provide a broad maximum starting point in understanding the potential for biofuel production in Hawaii. However, only a fraction of the total potential is needed to meet the desired displacements for 2010, 2015, and 2020 targets in the State of Hawai'i Act 240.

The maximum theoretical case for potential biofuels production potential in Hawai'i can serve as an important baseline to compare current consumption levels against. Table 1-7 below compares current fuel usage to the energy content in the maximum theoretical biofuel production case (cellulosic ethanol and fiber crops).

Table 1-7. Hawai'i Fuel Consumption, 2007.

Fuel	Fuel Consumption* (million gal/yr)	Energy Content (Btu/gal)	Percent of Maximum Biofuel Potential for Energy Crops
Gasoline	475	128,900	8%
Diesel (on & off highway)	66	140,300	2%
Jet Fuel	449	135,000	12%
Total All Petroleum Uses	2,222	135,000	59%

* Source: Energy Information Administration, U.S. DOE

From Table 1-7 it can be seen that displacing 20 percent of the gasoline consumption in Hawai'i would require about 8 percent of the maximum theoretical potential from energy crops. Displacing 20 percent of the diesel fuel would require a biofuel production capacity of approximately 2 percent of the maximum theoretical potential from energy crops. Meeting the State's goals under Act 240 for displacing 20 percent of gasoline and diesel fuel consumption combined, would require dedicating about 10 percent of the potential land available for energy crop production, based on the use of high-yielding energy crops. To gain a perspective on related land use issues, it can be noted that the Hawaii BioEnergy members collectively oversee 150,000 acres of land that they are evaluating for the production of energy crops and bioenergy products. The magnitude this land area is equivalent to 13.5 percent of the total Hawai'i agricultural land area identified for potential production of energy crops (i.e., 810,000 acres of non-prime and 300,000 acres of prime land, as noted earlier). Overall, it appears that meeting the State's goals under Act 240 for displacing 20 percent of gasoline and diesel fuel consumption with biofuels seems quite achievable.

1.5.3 Crop Specific Considerations

It is important to recognize potential benefits and drawbacks of energy crops considered in this evaluation. Sugar crops have been grown commercially in Hawai'i for decades. This means there is a significant amount of knowledge, as well as identified lands and equipment, for harvesting and processing sugarcane. In addition, food, biofuel, and usable electricity are all potential products of sugarcane. For these reasons, sugarcane production in is seen as one viable option as a feedstock for bioenergy production in Hawaii.

In order for oil seed crops such as Oil Palm and Jatropha to be competitive in Hawai'i, R&D would be needed to achieve higher yields per acre, reduce harvesting costs, and/or develop high-value co-products.

According to the analysis performed by the University of Hawai'i, Banagrass could be an attractive energy crop in Hawai'i, based on both potential yields and economics. One challenge is the difficulty in finding locations in Hawai'i where Banagrass will flower and seed. This poses a challenge for plant propagation and efforts to improve yields for this crop, which need to be explored further to confirm the promise for banagrass in Hawaii as a major energy crop alternative.

Sweet sorghum could offer strong potential as an energy crop for Hawaii. This crop alternative is in a relatively early stage of evaluation, and reliable data on its production potential was not available for this effort. Sweet sorghum readily produces seeds in Hawaii; and, with the potential for planting and harvesting two to three crops per year of sorghum in Hawai'i, this should enhance the ability to breed high-yielding varieties of sorghum that produce more tons per year of sugar and fiber per acre.

Biofuel production from microalgae is in the early stages of development. Researchers are still working to identify appropriate strains and develop production techniques that are not susceptible to invasive microorganisms or lower yielding algae strains that may be problematic. Most commercially produced algae is cultivated in raceway ponds which require level horizontal surfaces; the option of developing thousands of acres of algae ponds in Hawai'i is a distinct challenge, since much of the terrain is sloped. As noted earlier, algae has a number of advantages, including being able to use non-fresh water. In addition, algae can be used to capture waste carbon dioxide from the exhaust of power facilities.

1.5.4 Conclusions

It should be quite achievable for biofuels produced from in-state resources to displace 20 percent of the gasoline and diesel fuel needed for vehicle transportation in Hawai'i. This could be accomplished using about 10 percent of available agricultural land for energy crop production to supply the required biomass feedstock.

There are a variety of energy crops and biofuel conversion technologies that could be economically viable in Hawai'i. The State's unique and varied geography, microclimates, and infrastructure provide challenges in selecting and/or developing crops and conversion technologies for commercially viable production of biofuels. Efforts in the past to help the Hawaiian sugarcane industry address these state-specific challenges provide a useful model for the needs of an emerging biofuel industry in Hawai'i. The Hawaiian Sugar Planters' Association (now the Hawaii Agriculture Research Center (HARC)) developed sugarcane varieties that were adapted to 13 different environments in Hawai'i in order to address the range of microclimates and crop production challenges found in the State. A similar effort to identify and optimize energy crops for the varied environments in Hawai'i would help increase the likelihood that biofuel development reaches its full potential in offsetting petroleum dependency and fostering economic development centered on a new biofuel industry in Hawai'i.

The U.S. Department of Energy (DOE) and the National Renewable Energy Laboratory (NREL) are engaged in a major initiative to support the development of advanced biofuel conversion technologies in the U.S. With their expressed interest in seeing Hawaii become a model for bioenergy production, they could play a valuable role in ongoing efforts to identify and optimize conversion technologies suited to the economy-of-scale and varied requirements for biofuel development and expansion in Hawai'i.

In addition, identifying opportunities where some combination of biofuel, food, electricity, and high value products can be produced at the same facility could help make biofuel economics more favorable in specific circumstances.

2.0 Introduction

2.1 Background

This assessment of the potential amount of biofuels that could be produced in Hawai'i from in-state resources was prepared for the State of Hawai'i Department of Business, Economic Development, and Tourism (DBEDT) Strategic Industries Division. Act 240, SLH 2006, established a statewide alternative fuels standard that ramps up to 20 percent by 2020. This act called for DBEDT "to conduct a statewide multi-fuel biofuels production assessment of potential feedstocks and technologies, the economics of the various renewable fuels pathways, and the potential for ethanol, biodiesel, and renewable hydrogen production to contribute to Hawaii's near-, mid-, and long-term energy needs." This report represents the analysis called for by that legislation, focusing on the potential for biofuels production using a combination of waste biomass feedstocks available in Hawai'i, and energy crop production.

2.2 Objective

The objective of this project is to address the technical and economic prospects for biofuels production in Hawai'i using the State's existing and potential biomass energy resources for biofuels production. This includes a consideration of potential waste feedstocks, energy crops, biofuel conversion technologies, land and water availability, agriculture infrastructure, regulatory issues, potential markets, and local and federal policies and incentives. The information and analysis in this report is intended to assist DBEDT in defining a roadmap to meet the objectives and targets established by the alternative fuels standard created through Act 240.

2.3 Approach

The potential supply of biomass residues available in Hawai'i was inventoried in the report "Biomass and Bioenergy Resource Assessment for the State of Hawai'i;" prepared for DBEDT by the University of Hawai'i, Hawai'i Natural Energy Institute in 2002 (the report is available online at the following website -- www.hawaii.gov/dbedt/info/energy/publications/biomass-assessment.pdf). That report provided some useful baseline estimates of biomass residue availability, which has been updated in the following report. Biomass residue sources reviewed in this study include domesticated livestock wastes, forest products residues, agricultural residues, and urban wastes. Agricultural wastes addressed include those generated from sugar cane, pineapple, and macadamia nut processing. The urban waste category was subdivided into four types: municipal sold waste, food waste, sewage sludge or biosolids, and waste greases.

This report also evaluates the potential amount of dedicated crops that could be grown for biofuels production throughout the state of Hawai'i, including the estimated cost of producing these crops. There are many potential plant species that could be attractive as energy crops in Hawaii. Some crops are well known and substantial amounts of information and experience in growing these crops in Hawaii is available. In other instances, crops with significant promise have been identified and efforts to evaluate and field test productivity with the crops are underway. The crops considered for biofuel production represent sugar, fiber, and oil feedstocks. The potential energy crops identified for this report includes:

- Sugarcane (Saccharum officinarum)
- Banagrass (Pennisetum purpureum)
- Eucalyptus (Eucalyptus spp.)
- Leucaena (Leucaena leucocephala)
- Oil Palm (Elaeis guineensis), and
- Jatropha (Jatropha curcas)

These crops were selected for evaluation because of their potential for biofuel production in Hawai'i and because data is available for these crops in comparable climates to those present in Hawai'i. As information and field test data becomes available in the future for other crops that could be quite promising in Hawai'i (such as sweet sorghum or energy cane), the information in this report should be quite useful for comparing/analyzing the competitive merits of these alternative energy crop options.

In order to estimate the quantities of biofuels that could be produced in Hawai'i from energy crops, the amount of land that could potentially be used for energy crop production was evaluated. As a means for estimating Hawaii's biofuel generation potential, this report often focuses on the maximum theoretical potential based on full production of all identified lands. In reality, it will not be possible for all identified lands to be dedicated to production of energy crops because of competing uses for agriculture and grazing. The lands evaluated in this study fall in to two primary categories, prime irrigated agricultural lands and non-prime rainfed agricultural lands. Non-prime lands are examined first because it is believed that these lands would be most accessible for biofuel production. Prime irrigated lands have the advantage of producing significantly higher yields per acre than non-prime lands, but there is likely to be more competition for these lands with other forms of agriculture. It may be possible to use a portion of the prime lands for dedicated energy crops, and/or for producing food and fuel feedstocks with integrated crop and processing strategies.

Across the Hawaiian Islands there are substantial variations in temperature and precipitation that will have significant bearing on the types of energy crops that can be successfully grown and the annual quantities of biomass that can be produced on specific island locations. To evaluate the prime irrigated and non-prime rainfed options, soil classifications were considered based on typical ambient temperatures and average moisture conditions. This approach was also helpful in identifying the most appropriate or promising pairings of different land types with different crops.

There are also significant variations in the suitability of soils for crop production, as well as substantial variations in land slope that will impact the ability to grow and harvest energy crops. To address these variations in microclimate, soil conditions, and land slope, geographic information system (GIS) software was used to evaluate energy crop suitability and energy crop productivity on land zoned for agriculture. The crop production potential for rainfed non-prime agricultural land, and irrigated prime agricultural land was quantified on each island.

Sugar feedstocks, such as sugarcane, can be used to produce ethanol through a conventional fermentation process. Fiber crops such as Banagrass, Eucalyptus and Leucaena can be used to produce ethanol through biochemical or thermochemical conversion processes. For oil feedstocks such as Oil Palm and Jatropha, transesterfication can be used to produce biodiesel. Table 2-1 below shows the conversion pathways evaluated for each identified feedstock.

Table 2-1. Biomass Conversion Technology Summary.

Crop Type	Conversion Pathway	Product	Commercialization Status
Sugar			
Sugarcane	Conventional Fermentation	Ethanol	Commercial
Fiber			
Banagrass Eucalyptus Leucaena	Enzymatic Hydrolysis & Fermentation or Thermochemical Conversion	Ethanol	Near Comercial, Demonstration Phase
Oil			
Oil Palm Jatropha	Transesterification	Biodiesel	Commercial

It should be noted that while conventional fermentation and transesterfication are commercially available, various biochemical and thermochemical pathways for ethanol production are still in the demonstration or pre-commercial phase.

Finally, efforts were made to estimate both the cost of production for each type of biomass and the cost of converting this biomass to biofuels. For breakeven analysis, the assumption was made that the market price of ethanol would be $2.41/gallon. These economic evaluations help to identify the most promising opportunities for near term biofuel production from energy crops in Hawai'i.

3.0 Biomass Conversion Technology Options and Issues

There are a variety of different biofuels and conversion pathways for biofuel production from available biomass resources in Hawai'i. Each technology has certain benefits, constraints and feedstock requirements, which are discussed in further detail below. Table 3-1 summarizes the biomass conversion technologies discussed in this report. Table 3-2 below shows the density and energy content of different liquid fuels.

Table 3-1. Biomass Conversion Technology Summary.

Fuel	Conversion Pathway	Commercialization Status
Ethanol	Conventional Fermentation	Commercial
Ethanol	Enzymatic Hydrolysis	Pre-Commercial
Ethanol	Thermochemical	Pre-Commercial
Biodiesel	Transesterification	Commercial
Renewable Diesel	Fischer-Tropsch	Pre-Commercial
Hydrogen	Methane Reformation	Commercial
Hydrogen	Biomass Gasification	Pre-Commercial
Hydrogen	Microorganisms	Research & Development

Table 3-2. Energy Content of Liquid Fuels.

Fuel	Density (lb/gal)	Energy Content (Btu/gal)
Ethanol	6.58	84,300
Biodiesel	7.50	127,700
Gasoline	6.16	128,900
Diesel	7.02	140,300
Jet Fuel	6.71	135,000

3.1 Ethanol

Ethanol is an alcohol that can be used as a high-octane fuel, either blended with gasoline or alone. Ethanol is traditionally made via fermentation of sugar- or starch-containing feedstocks such as sugarcane or corn. There are also emerging technologies to produce ethanol from cellulosic biomass feedstocks, such as wood, corn stover or bagasse, through either a biochemical or thermochemical mechanism.

3.1.1 Conventional Fermentation

Conventional fermentation is a biochemical reaction whereby microorganisms (usually yeasts) break down sugars to make ethanol and carbon dioxide. After fermentation, the mixture is distilled or mechanically separated to recover alcohol from the reactor solution. For transportation fuel applications, pure ethanol is mixed with a denaturant to render it unfit for human consumption.

In Hawai`i, the principal feedstock for conventional fermentation is sugar from sugarcane. Although there is not a significant amount of ethanol being produced from sugar feedstocks currently in Hawai'i (or elsewhere in the United States), Brazil and other countries are actively producing ethanol from sugarcane, sugar beets, and molasses. This demonstrates that it can be economically feasible to produce ethanol using these feedstocks. However, the economic drivers for ethanol production in Hawai'i are sufficiently different from those in Brazil to make direct economic comparisons difficult, as discussed in more detail later in the following section.

3.1.2 Advanced Processing Technologies

Ethanol can also be produced via emerging technologies that utilize the carbohydrates locked in cellulose and hemicellulose polymers found in plants. As an example, bagasse is a fibrous sugar cane residue that cannot be converted to ethanol via traditional fermentation. While it is currently burned in recovery boilers to produce process steam, advanced cellulosic ethanol technologies process bagasse to produce additional ethanol. Ethanol produced from these technologies is known as "cellulosic ethanol." Much attention is currently focused on commercializing cellulose-to-ethanol technologies, which are described in greater detail below.

At present, there is limited information in the public domain regarding process characteristics of advanced ethanol processing technologies, and only a fraction of the information available is of a quantitative nature. In large part this is because these technologies are still emerging and are not yet commercially established. Few of the technology suppliers have begun construction of commercial-scale facilities, much less begun commercial operation. Therefore, none of these technologies has been successfully operated at scale to provide empirical performance that verifies the theoretical performance suggested by process simulations. In addition, nearly all of the developers of these technologies are private entities with little, if any, incentive to disclose the process features that provide them with competitive advantage.

Hydrolysis

Hydrolysis is the chemical process that breaks down biomass polymers into component sugars. The hydrolysis breaks down cellulose and hemicellulose into simple sugar compounds that can be fermented to ethanol. There are two principal hydrolysis technologies: enzymatic hydrolysis and acid hydrolysis.

Enzymatic hydrolysis uses specific protein compounds (cellulose enzymes) to break down complex carbohydrates. A recent technical development has been the introduction of simultaneous saccharification and fermentation (SSF). In SSF, cellulose enzymes and fermenting microbes are combined in the same reaction vessel. As sugars are hydrolyzed, they are immediately fermented to ethanol.

Acid hydrolysis uses strong acids to break down cellulose and hemicellulose. The process can use either concentrated acid or dilute acid. Dilute acid hydrolysis is the oldest cellulosic ethanol technology. In dilute acid systems the acid is typically neutralized in the final process stage, whereas with concentrated acid systems, the acid is recaptured and recycled, while the sugars are neutralized and funneled to a fermentation reactor.

Thermochemical

Another way to produce cellulosic ethanol is by thermally breaking down lignocellulosic material into syngas (gasification) and catalytically converting the syngas to alcohols. Gasification refers to the process in which biomass is heated in an oxygen-starved environment to produce a mixture of carbon monoxide and hydrogen, known as syngas. The oxygen content allowable for gasification is about one-third of the oxygen needed for normal combustion. The syngas is catalytically reacted in a modified Fischer-Tropsch synthesis process to make alcohols. Ethanol can then separated from other alcohols and by-products. Compared to biochemical conversion technology, thermochemical technology has the advantage of being able to convert the lignin that binds the cellulose and hemicellulose material together into syngas and liquid fuel, as well as converting the cellulose and hemicellulose to syngas and liquid biofuel, whereas hydrolysis converts only the cellulose and hemicellulose to the plant matter, and another use must be found for the lignin by-product (typically the lignin will be used as fuel to meet the energy needed for the conversion process).

Thermochemical ethanol conversion has not yet been successfully demonstrated at commercial scales, although there are many companies that have constructed pilot-scale plants and are initiating construction of demonstration-scale plants. In Hawai`i, Gay & Robinson is working with Clear Fuels Hawai'i to construct a demonstration-scale gasification facility for the production of cellulosic ethanol from bagasse.

3.1.3 Feedstock Suitability

For conventional ethanol, feedstocks that are high in sugar or starch, such as sugarcane, sugar beets, molasses, or corn, are suitable for fuel production. In Hawai`i, sugarcane is viewed as the preferred crop for sugar-based ethanol production, while molasses is also a suitable feedstock.

For cellulosic ethanol, potential feedstocks include any lignocellulosic material, including wood, energy crops, fibrous agricultural waste, and other municipal waste streams. Sugarcane fiber, Banagrass, and Eucalyptus trees are some of the primary cellulosic feedstocks that have been studied as potential sources in Hawai'i. Agricultural wastes and municipal wastes are potentially attractive for the production of ethanol, as they can often be obtained at lower costs than dedicated biomass energy crops.

3.1.4 Anticipated Cost Competitiveness

Ethanol is the most widely used biofuel and has the most mature markets when compared to biodiesel and biomass-derived hydrogen. Some components of the ethanol cost structure are outline below. A summary of the estimated costs for different ethanol conversion technologies is outlined in Table 3-3.

Currently, a large number of technology suppliers are competing to become the first commercial facility to produce ethanol from cellulosic feedstocks via a second generation process. Most technologies remain at the pilot or demonstration stage. Commercial data for ethanol yield, capital cost, operating cost, and efficiency for different advanced processing technology companies has not been firmly established, so estimates for these figures are expressed in ranges.

Advanced ethanol technologies are not currently cost competitive with conventional ethanol technologies. Although both hydrolysis and thermochemical processes have promise, the capital cost are significantly higher than conventional fermentation. However, substantial development efforts are underway to reduce capital costs and improve performance in the effort to commercialize advanced cellulosic processes. Key advantages of advanced technologies are that they can utilize lower-value feedstocks that can be considerably less expensive than sugar or starch feedstocks, and the amount of cellulosic material that can be obtained per acre and from various sources is much greater than the amount of sugar or starch that can be produced – thus the use of cellulosic feedstocks could significantly increase the amount of biofuels that could be produced on Hawai'i. The U.S. Department of Energy has set a cost target of $1.33 per gallon by 2012 for cellulosic ethanol, and $1.17 per gallon by 2017. DOE has estimated that at this price cellulose is can be competitive.

Table 3-3. Hawai'i Ethanol Conversion Cost Estimates Summary.

Conversion Pathway	Feedstock Costs ($/gal ethanol)	Capital Cost ($/gal annual capacity)	O&M Cost ($/gal ethanol)
Conventional Ethanol (Raw sugar)	1.50	2.10 – 2.40	0.90
Enzymatic Hydrolysis[1]	0.31[2]	4.00 – 8.00	0.35
Thermochemical[3]	0.31[4]	4.00 – 8.00	0.70 – 1.00

Notes:
1 Assumes bagasse feedstock
2 Assumes 80 gal/ton yields. Bagasse price is $25/ton, approximately equal to the avoided cost of coal.
3 Assumes bagasse feedstock
4 Assumes 80 gal/ton yields. Bagasse price is $25/ton, approximately equal to the avoided cost of coal.

Feedstock Costs

For mainland US conventional ethanol production, corn is the primary feedstock. The most likely feedstock for ethanol production in Hawai'i is sugarcane, although there has been a steady decline in land used for sugarcane crops since 1990 (see Figure 3-1). The price of US sugar has been above world sugar prices because of government support for domestic production. During the 2000s, US raw sugar prices have ranged from 19 to 22 cents per pound. One gallon of ethanol can be produced from 14 pounds of sugar, equating to approximately 140 gallons of ethanol per ton of sugar. On a raw feedstock basis, one ton of unprocessed sugarcane stalks yields around 20 gallons of ethanol. Comparatively, one ton of molasses with 50 percent fermentable sugars yields about 70 gallons of ethanol.

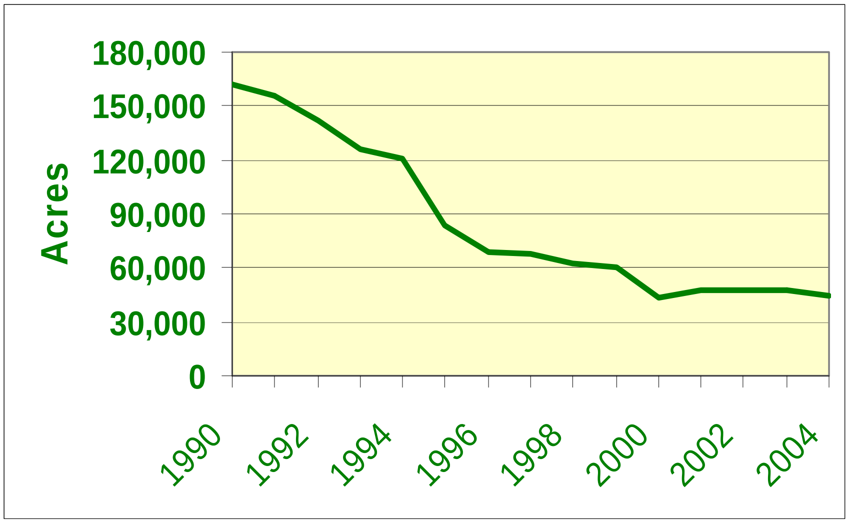

Figure 3-1. Decline in Hawaiian Sugar Cane Land (Source: Gay & Robinson).

For cellulosic ethanol, feedstock costs vary greatly depending on location. Ethanol plants will be more economical if located at or near sugarcane processing facilities. Transportation costs can be high for biomass, particularly feedstocks such as bagasse with low density and/or high moisture content. The transportation component of the total delivered cost can be greater than the raw resource cost for low value feedstocks.

In Hawai`i, the power generation sector would be a competitor with the cellulosic ethanol sector for biomass wastes, as the state Renewable Portfolio Standard requires a portion of electricity be generated by renewable sources, which could include biomass. It is likely that the competition for cellulosic feedstocks will put upwards pressure on biomass prices. As bagasse is currently used as boiler fuel for sugar processing, its minimum cost would be the cost of replacement boiler fuel if the bagasse were used to produce biofuels.

Capital Costs

Traditional sugarcane ethanol plants costs have been estimated by the USDA to be around $2.40[1] per annual gallon of capacity. This is higher than corn-based ethanol plants ($1.50 per gallon) primarily due to higher feedstock preparation equipment costs.

Developmentally, thermochemical cellulosic ethanol plants are still in the demonstration stage. As such, it is difficult to estimate the capital costs of future commercial facilities. Enzymatic hydrolysis plants are not yet fully commercialized. The capital costs for cellulose-to-ethanol plants are currently estimated to be in the range of $4.00-$8.00 per gallon. Many are expecting capital costs for both enzymatic and thermochemical ethanol plants to become competitive with traditional ethanol plants by 2012.

O&M Costs

Ethanol production from sugarcane requires less steam and electricity than sugar production. In addition, sugarcane trash can be either combusted for electricity or further processed to produce cellulosic ethanol, depending on which option is technically and economically advantageous. As one ton of bagasse is approximately equivalent to one barrel of oil on an energy basis, there may be opportunities to use a different energy sources for the generation of steam and electricity while converting bagasse to ethanol. While replacing bagasse with another energy source that must be purchased would increase operating costs, the sale of ethanol provides additional revenue. This tradeoff may be attractive.

[1] "The Economic Feasibility of Ethanol Production from Sugar in the United States", USDA, July 2006.

In the report "The Economic Feasibility of Ethanol Production from Sugar in the United States" published by the USDA, the average cost to produce ethanol from sugarcane in Brazil was estimate to be $0.81 per gallon, including feedstock processing costs and excluding capital costs. The operating costs in Hawai'i would likely be higher than in Brazil, as labor costs are greater. Additionally, the USDA estimates the processing costs to produce ethanol from molasses at $0.91 per gallon. For comparison, the production cost for dry milling of corn has been around $1.05 per gallon of ethanol, with 50 percent of the cost resulting from corn procurement and 50 percent resulting from processing costs (it should be noted that corn prices have doubled over the last year or so, in large part to due to strong demand for corn-to-ethanol production, which raises the cost to about $1.50 to produce a gallon of ethanol from corn at current prices). Processing costs in sugarcane ethanol plants are lower because it is easier to make ethanol from sugar than from starch in grains, even if capital costs are higher.

Until recently the cost of cellulose-digesting enzymes has been a key barrier to economic production of ethanol via enzymatic hydrolysis. Many companies are working on developing processes to substantially reduce enzyme costs to improve process economics. For example, Novozymes and Genencor have created genetically modified organisms to produce large quantities of cellulose-digesting cellulase enzymes. With this breakthrough, the cost of enzymes dropped from around $5/gal ethanol to around $0.15-$0.30/gal ethanol. Still, it appears that economic competitiveness of enzymatic hydrolysis may be several years away.

Gasification processes tend to be relatively energy intensive, typically requiring substantial amounts of electricity, process steam, and water. Energy costs can be substantially reduced by extracting a portion of the syngas to use as fuel to meet process steam/energy requirements. Although this would reduce the ethanol output by roughly one-third, it would substantially avoid the need for other fuels, lowering O&M costs.

Predicted Costs

The costs of for advanced cellulose-to-ethanol technology are predicted to decrease given the significant research and development efforts underway through government and private sector initiatives. Figure 3-2 and Figure 3-3 illustrate NREL/DOE cost projections for enzymatic hydrolysis processes and gasification/alcohol synthesis processes respectively. NREL's recent projections are that it will cost approximately $1.49 per gallon in year 2012 to produce ethanol from cellulosic biomass through enzymatic hydrolysis. Of this, the feedstock costs accounts for approximately $0.60 per gallon, conversion costs are expected to account for the remaining $0.89 per gallon. The production of ethanol through thermochemical means is expected to cost slightly more at $1.57 per gallon through this same timeframe. Of this the feedstock costs account for $0.71 per gallon and the conversion costs account for $0.89 per gallon.

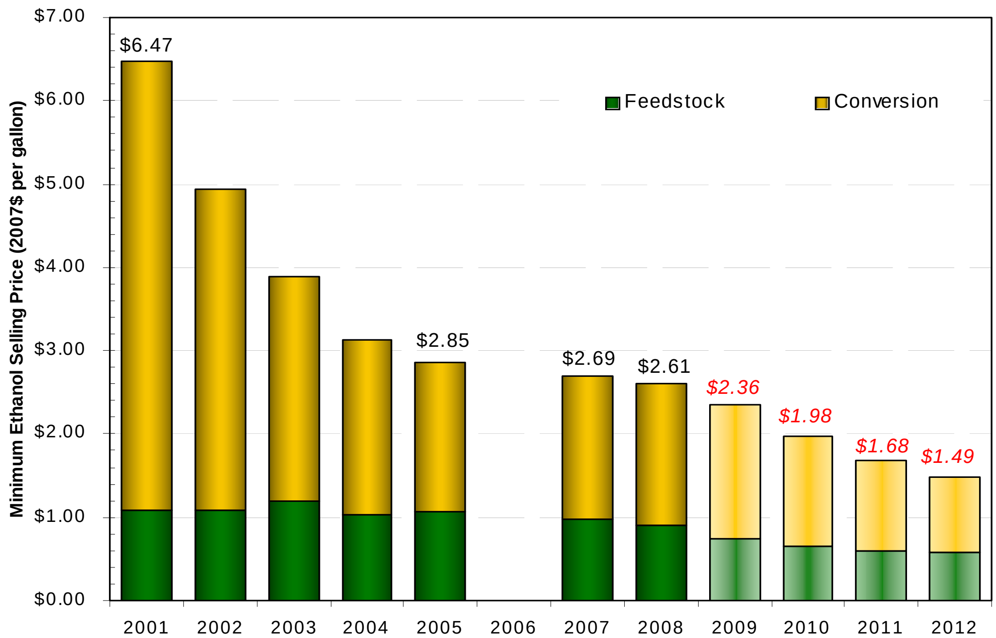

Figure 3-2. Projected Costs of Cellulosic Ethanol Production, Biochemical Pathways (Source: NREL).

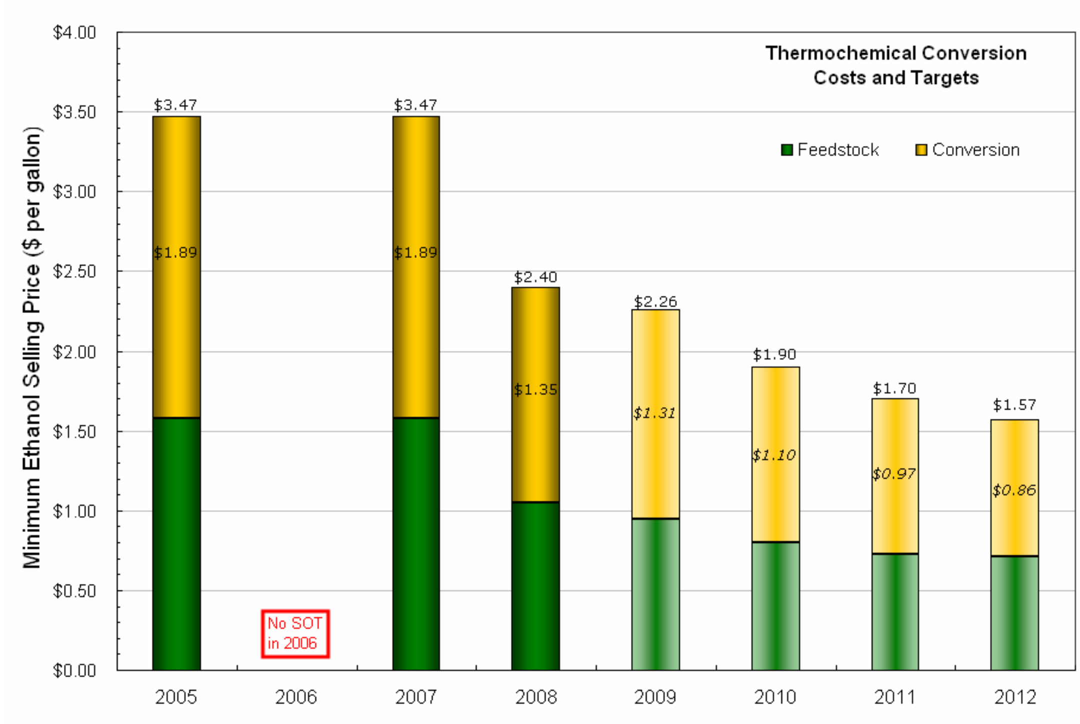

Figure 3-3. Projected Costs of Cellulosic Ethanol via Thermochemical Pathways (Source: NREL).

3.1.5 Ethanol Production Potential

The anticipated conversion rates for ethanol are listed in Table 3-4. Second generation ethanol technologies are still being developed and have exhibited a range of yields at different scales of production.

Table 3-4. Ethanol Yields.

Conversion Pathway	Feedstock	Typical Yield (gal/dry ton feedstock)
Conventional Ethanol	Raw sugar	135
Conventional Ethanol	Molasses	69 – 72
Enzymatic Hydrolysis	Bagasse	60 – 90*
Thermochemical (self-sufficient)	Bagasse	80 – 95**
Thermochemical (maximum alcohol)	Bagasse	110 – 130**

Notes:

* Lignin is used to provide process steam and power.

** Some of the syngas is diverted to provide process steam for self-sufficient operation. Under the maximum alcohol operation, natural gas is used for process steam and all syngas is converted to alcohol. Other alcohols are typically produced in addition to ethanol, particularly methanol.

It is expected that ethanol yields will increase as further development efforts improve the processes. For example, the DOE estimates yield increasing up to 104 gal/dry ton feedstock by the year 2020 for both biochemical and thermochemical pathways (see Figure 3-2 and Figure 3-3). By 2030, the targets are 115 gal/dry ton. These figures predict improvements in both feedstock characteristics and process engineering.

3.1.6 Other Potential Products

Methanol is an alcohol related to ethanol. Methanol can easily produced from syngas via catalytic reactions. Methanol has multiple potential uses. Methanol can be used as a fuel directly; alternatively, it is an important feedstock for the production of biodiesel (representing about 10 to 20 percent of the feedstock used to make vegetable oil into biodiesel via transesterification); and methanol has value in the chemical commodity market. Many other complex organic compounds utilize methanol as building blocks or reactants.

Second generation ethanol technologies can also produce steam and power as co-products. For the hydrolysis pathway, the lignin component separated out of the cellulosic biomass can be a useful boiler fuel to produce process steam and electricity in excess of process requirements. The excess electricity can be fed directly to the grid as renewable power. For the gasification pathway, syngas can be diverted from ethanol production to fire a boiler for process steam and power generation. Although diverting syngas for the production of process heat reduces ethanol yield, this also reduces the use of fossil fuels in the production of ethanol.

3.2 Biodiesel

Biodiesel is a fuel refined from vegetable oils (soy, rapeseed, palm, etc.) or animal fats. It is a nontoxic, biodegradable, and renewable fuel that can be used in diesel engines with little or no modification. The use of biodiesel for transportation applications is a relatively new phenomenon but is gaining acceptance and growing rapidly. To put the growth of this market into context, as recently as 2004 total biodiesel production capacity amounted to only 25 million gallons per year (MGY). According to the National Biodiesel Board (NBB), as of January 2008, there were 171 companies with biodiesel manufacturing plants in the U.S. with installed capacity of 2.24 billion gallons per year. According to NBB, actual biodiesel production in fiscal year 2007 was 450 million gallons. By comparison, total distillate fuel consumption in the US is about 60 billion gallons per year; and for the state of Hawai'i total distillate fuel consumption for all uses was about 307 MGY in 2005.

3.2.1 Conventional Biodiesel Transesterification

Transesterification is the most common way of producing biodiesel. In transesterification, an alcohol, such as methanol, is reacted with the oil over the presence of a catalyst, usually sodium or potassium hydroxide. This chemical reaction results in glycerin (co-product) and methyl esters (biodiesel compounds). The methyl esters are collected, washed, and filtered to yield pure biodiesel. The glycerin co-product has several commercial uses in the cosmetics and chemicals industries, and research is underway to explore new options for converting glycerin into fuel(s) or higher value chemicals.

3.2.2 Other Renewable Diesel Technologies

Fischer-Tropsch (FT) diesel is produced from synthesis gas ("syngas", a mixture of mostly CO and H_2) derived from the gasification of carbonaceous materials, such as coal, biomass or natural gas. Based on the feedstock used, it is also known as CTL ("coal to liquid"), GTL ("gas to liquid"), BTL ("biomass to liquid"), or some combination of these routes. The term Fischer-Tropsch refers to a catalytic reaction where carbon monoxide and hydrogen gas are converted to hydrocarbon chains. The main process reaction is the following:

$$(2n+1)H_2 + nCO \rightarrow C_nH_{(2n+2)} + nH_2O$$

The reaction produces a range of different hydrocarbon fractions, but consists largely of diesel, jet fuel, and low-octane gasoline (naphtha). FT diesel is virtually sulfur free and has the same viability and functionality as diesel fuel. The main combustion property of the fuel, the cetane index, is typically near 70. This is superior to most on-road diesel blends which have cetane indexes of 40 to 50. Greater detail for the economics and design of a BTL plant is presented in Section 3.4.

Other technology options are available for the production of diesel fuel, although none have the commercial experience or economic potential as esterification and FT. Greater detail for other alternatives will be presented later in this section.

3.2.3 Economics of Using On-Island Resources Compared to Imported Vegetable Oils

To the extent possible, using on-island resources for biofuel production is preferable to using imported resources. However, there is a low volume of animal fats and vegetable oils currently produced in Hawai`i. For ethanol markets, Gay & Robinson has estimated that ethanol produced locally in Hawai'i enjoys a $0.15 to $0.25 per gallon freight advantage over imported ethanol, depending on the island. It is expected that biodiesel produced locally using local feedstocks would enjoy a similar cost advantage over imported biodiesel or local biodiesel manufactured from imported vegetable oils.

3.2.4 Feedstock Suitability

As noted earlier, biodiesel can be produced from oils and sources of free fatty acids, such as animal fat, vegetable oils, and waste greases. Algal oil is another feedstock that has been investigated for technical and economic feasibility. There is ongoing research into algal oil and results look promising, but commercialization is likely several years away. Essentially all types of triglycerides or free fatty acids are suitable to make biodiesel.

Animal fats and waste vegetable oils make excellent feedstocks for biodiesel because they are low value products. Used oil from restaurants and eateries can be obtained at low costs. Tallow and chicken fat are low value products from animal rendering and poultry industry, respectively that are suitable feedstocks for biodiesel production.

Suitable feedstocks for Fischer-Tropsch diesel are virtually the same as those for thermochemical (gasification-based) ethanol production. Any lignocellulosic material, including wood, energy crops, agricultural waste, and other municipal waste streams are potentially suitable.

3.2.5 Anticipated Cost Competitiveness

Historically, biodiesel has not been economically competitive compared to petroleum diesel without some type of governmental incentive. However, rising petroleum oil prices, geopolitical concerns, and oil price volatility are improving biodiesel economics. However, it is unlikely that there is enough waste oil and tallow to be a major feedstock for biodiesel production in Hawai'i. A summary of the costs of biodiesel and Fischer-Tropsch diesel conversion technologies is outlined in Table 3-5.

Table 3-5. Hawai'i Biodiesel Conversion Cost Summary.

Conversion Pathway	Feedstock Costs ($/gal)	Capital Cost ($/gal annual capacity)	O&M Cost ($/gal)
Transesterification*	0.45 – 0.55	0.80 – 1.20	0.20 – 0.40
Fischer-Tropsch Diesel**	0.29	2.50 – 3.50	0.70 – 1.00

Notes:
* Assumes waste oil
** Assumes bagasse. Bagasse price is assumed to be approximately $25/ton, approximately equal to the avoided cost of coal.

Feedstock Costs

The largest biodiesel production cost component is for the oil or fat feedstock (see Figure 3-4). Depending on the size of the biodiesel production facility and the feedstock used, the feedstock cost can account for up to 75 to 85 percent of the total production cost per gallon.

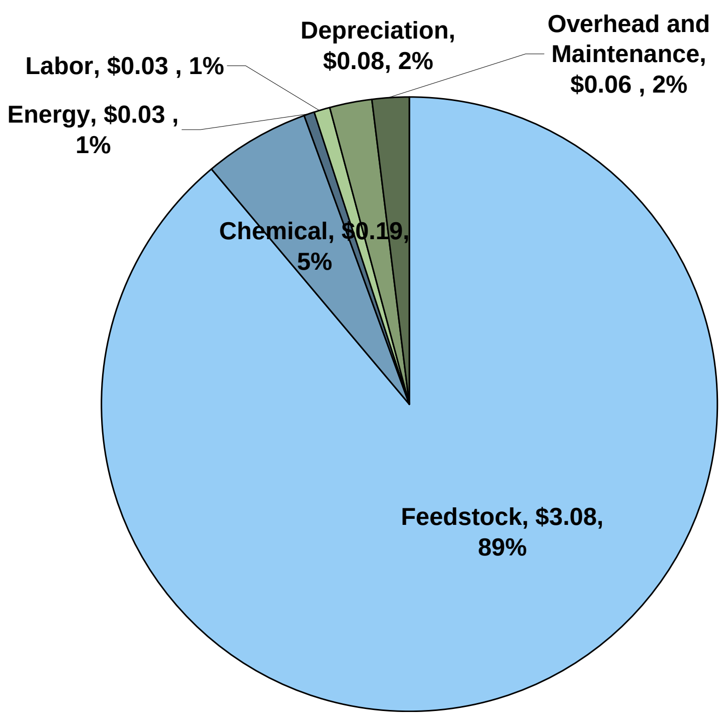

Figure 3-4. Production Cost Distribution ($/gal) for a Typical 30 MGY Soy Biodiesel Plant (Adapted from *Building a Successful Biodiesel Business*).

Malaysian palm oil has been the cheapest oil-based feedstock, but prices have been on the rise, as shown in Figure 3-5. Several Asian countries have passed legislation to promote biofuel use, which has greatly increased palm oil demand. Moreover, there is social pressure to prevent farmers from destroying rain forests to make more room for oil crops, limiting supply growth.

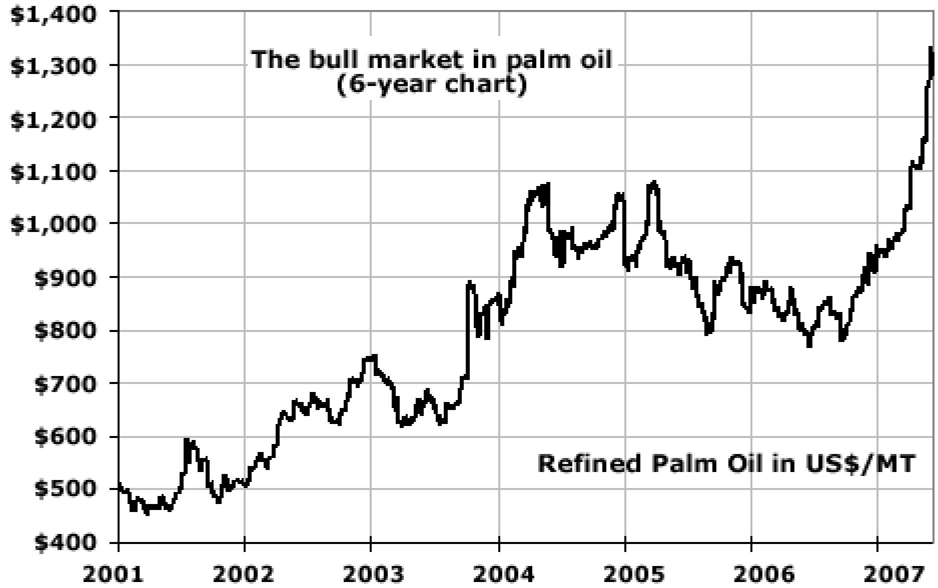

Figure 3-5. Historical Palm Oil Prices[2]

Feedstock prices are largely tied to commodity markets and many oils have competing markets in the food industries. As such, their prices are constantly shifting. For example, soybean oil prices increased nearly 50 percent from 2006 to 2007. Waste oil, fats, and grease are generally cheaper than vegetable oil, but their quantities are substantially limited.

As more and more biodiesel facilities become operational, increasing demand for feedstocks will maintain upward pressures on the vegetable oil and animal fat commodity markets. In Hawai'i, there are currently two biodiesel facilities utilizing waste oil and grease as the principle feedstock: one is on O`ahu, the other is on Maui. Both plants are owned and operated by Pacific Biodiesel.

Capital Costs

Biodiesel facilities are relatively simple and easily scaled to meet local needs. The process occurs at low temperature and pressure, which keeps costs relatively modest. Two kinds of biodiesel production facilities are in operation today: batch plants and continuous flow plants. Batch plants tend to be much smaller than continuous flow plants and produce discrete "runs" of biodiesel. Continuous flow plants are usually much

[2] Source: DailyWealth.com, June 2007, http://www.dailywealth.com/archive/2007/jun/2007_jun_15.asp

larger, run continuously, and are capable of implementing more efficient processes than those used in batch operations. At about $1/gallon, capital costs for biodiesel facilities are relatively low.

O&M Costs

After feedstock costs, chemical costs (primarily methanol and catalyst) represent the second largest contributor to biodiesel production costs at 10-15 percent of the overall costs. Other production costs include equipment, energy, labor, and overhead and maintenance. The O&M costs for biodiesel range from $0.20 to $0.40 per gallon.

Predicted Costs

Biodiesel prices are expected to continue to rise. Although current generation biodiesel facilities are more efficient and benefit from economies of scale, feedstock costs have remained high as competition has intensified. As biodiesel is particularly sensitive to volatile feedstock costs, many smaller-scale biodiesel operations have shut down in the US and Europe recently. The US biodiesel industry depends a great deal on incentives such as the blender tax credit.

3.2.6 Biodiesel Production Potential

The current conversion rates for biodiesel are listed in Table 3-6. Fischer-Tropsch diesel processes are still being developed and have exhibited a range of yields at different scales of production.

Table 3-6. Biodiesel Yields.

Conversion Pathway	Feedstock	Typical Yield (gal/ton feedstock)
Transesterification	Waste oil	250 – 280
Fischer-Tropsch Diesel	Bagasse	75 – 89*

Notes:
* Assumes an energy self-sufficient process that diverts approximately 28% of the syngas to generate process steam.

3.3 Biomass-Derived Hydrogen

Hydrogen offers potential as a fuel for vehicles, either for direct combustion engines or fuel cell-based vehicles. Hydrogen is gaseous, flammable fuel that produces water vapor when it is combusted. Although hydrogen is not used commonly as a fuel for transportation or electric generation, it holds promise as a clean-burning option. Hydrogen can be obtained from both biomass and fossil fuels, but this study will focus on hydrogen derived from biomass.

3.3.1 Methane Reformation

Methane reformation is the reaction of methane with steam to yield carbon monoxide and hydrogen. Natural gas is the most common source of methane for reformation, but in the context of this report, methane is considered to be derived from biomass sources (i.e. landfill gas or biogas derived from anaerobic digestion). The reaction is carried out under pressure in the presence of a catalyst. Because the reaction is endothermic, heat must be supplied to the process for propagation. Methane reformation is often combined with a water-gas shift reaction and pressure-swing adsorption to maximize hydrogen and remove impurities. For biomass-derived hydrogen, the methane is obtained from anaerobic digestion or landfill gas collection.

Since the amount of methane currently available in Hawai'i is relatively small, hydrogen from methane reformation is not a strong biofuel option, at least for the near term. However, the hydrogen available in Hawaii's waste-to-methane sources may play a role in niche markets, such as fuel cells.

3.3.2 Biomass Gasification

Biomass gasification is the most common route to produce hydrogen from biomass. As described earlier, biomass gasification refers to the process in which biomass is heated in an oxygen-poor environment to produce a mixture of carbon monoxide and hydrogen, known as syngas. The oxygen content allowable for gasification is about one-third of the oxygen needed for normal combustion. Similar to methane reformation, biomass gasification can be combined with a water-gas shift reaction to maximize hydrogen yield.

This is similar to the process to produce thermochemical cellulosic ethanol (see section 3-2). However, instead of further reacting the hydrogen with carbon monoxide to make alcohol compounds, the hydrogen is separated from the carbon monoxide.

3.3.3 Microorganisms

There are microbes such as green algae and cyanobacteria that can produce hydrogen gas as a byproduct of metabolic activities. These microorganisms produce hydrogen by different mechanisms, but they are catalyzed by the enzymes nitrogenase or hydrogenase. This technology is still in early stages of R&D. The technology is promising, but will require significant additional research before large-scale hydrogen production is feasible.

3.3.4 Feedstock Suitability

For methane reformation, the methane would likely come from landfill gas or anaerobic digestion. Landfill gas is less expensive and more commercially ready than anaerobic digestion on Hawai`i. The Landfill Methane Outreach Program administered by the EPA lists 14 landfills that have potential for methane collection for energy use. Anaerobic digestion can utilize municipal solid waste, sewage, or animal manure to produce methane. There is little activity currently going on in Hawai'i with anaerobic digestion of animal manure.

Feedstocks suitable for hydrogen produced via biomass gasification are the same ones suitable for cellulosic ethanol. Any lignocellulosic materials, including wood, energy crops, agricultural wastes, and other municipal waste streams are good feedstock candidates. Sugarcane fiber, Banagrass, and Eucalyptus trees have been studied as potential sources.

Microorganisms that generate hydrogen need an environment conducive to sustained metabolic propagation. Some species can withstand a wide range of physical conditions, while others are highly susceptible to poisoning or thermal disturbance. Feedstocks free of foreign substances are most suitable for hydrogen produced from microorganisms.

3.3.5 Anticipated Cost Competitiveness

Nearly 95 percent of the hydrogen produced today in the US is made via steam methane reformation, mostly from natural gas. Most of the hydrogen is used for petroleum refining and ammonia production for fertilizer.

Currently there is little infrastructure in Hawai'i to use hydrogen as a major fuel. Considering all the upgrades necessary for production, distribution, and transportation, hydrogen produced from biomass is not expected to be a cost-competitive fuel for transportation for some time.

Table 3-7. Hawai'i Hydrogen Production Cost Summary.

Conversion Pathway	Feedstock Costs	Capital Cost ($/m^3 H_2 annual capacity)	O&M Cost
Methane Reformation	$2 - $5/MMBTU landfill gas	25	$0.0075/m^3 hydrogen*
Biomass Gasification (bagasse)	$25/ton bagasse	30 – 32	$0.0086 – 0.0093/m^3 hydrogen*
Microorganisms**	Unknown	Unknown	Unknown

Notes:
* HHV of hydrogen is 12,000 BTU/m^3.
**Still in R&D phases of development.

Feedstock Costs

For this study, the feedstock that appears most viable for methane reformation is landfill gas. The price of landfill gas ranges substantially across the US and is affected by landfill characteristics, landfill ownership, alternate uses for the landfill gas, environmental regulations, among other things. Some utility-owned landfills have essentially given away their landfill rights to project developers who have agreed to operate and maintain landfill gas collection systems. Others landfills have indexed landfill gas contract price to the price of natural gas, expressed as a $/MMBTU basis. A price range of $2 to $5 per MMBTU can be considered indicative of landfill gas feedstock prices.

Capital Costs

Natural gas methane reformation is a commercial process and as such the capital costs are fairly well known. Utilizing landfill gas or digester gas is less common, but much of the same processing and equipment can be used to isolate hydrogen with the addition of gas cleanup equipment.

The process to produce hydrogen via biomass gasification is similar to the process to the process to produce cellulosic ethanol via gasification. Hydrogen production does not require catalytic conversion of syngas to alcohols, but does have greater gas cleanup requirements if landfill gas is the feedstock. If bagasse is the feedstock, there is additional equipment required for solids handling and enhanced gas cleanup, which increases the overall capital cost.

Hydrogen production processes using microorganisms are still in R&D phases. The capital costs are not yet well known, but the capital costs would need to allow the economics to converge on the price of hydrogen produced via other pathways.

O&M Costs

O&M costs for methane reformation run on the order of $0.0075/m^3 of hydrogen produced. This equals approximately $0.62/MMBTU of hydrogen.

Similar to capital costs, the O&M costs for hydrogen production from biomass gasification range from 15 to 30 percent higher because of the additional solids handling and gas cleanup. O&M costs for microorganisms are not well known at this time.

Predicted Costs

A mature market for hydrogen currently does not exist in Hawai'i. As the industry is limited, it is difficult to project hydrogen prices. Several markets are positioned as potential large-scale users of hydrogen, including transportation and electric generation. However, there is little infrastructure to utilize hydrogen on a large scale in the near term.

If large scale hydrogen production ramped up in the wake of increased industrial usage, costs would likely decrease because of economies of scale. However, the hydrogen market is not likely to grow substantially in the near term, so hydrogen prices will likely remain relatively flat or increase slightly.

3.3.6 Hydrogen Production Potential

The current conversion rates for hydrogen are listed in Table 3-8. Gasification and microorganism pathways for hydrogen are still being developed and have exhibited a range of yields at different scales of production.

Table 3-8. Hydrogen Yields.

Conversion Pathway	Feedstock	Typical Yield
Methane Reformation	Landfill Gas	3 scf/scf landfill gas
Biomass Gasification	Bagasse	787 m^3/dry ton bagasse*
Microorganisms	Cellulosic wastes	Unknown

Notes:

* D. Bowen, F. Lau, R. Dihu, S. Doong, R. Remick, R. Silmane, R. Zabransky, E. Hughs, and S. Turn, "Techno-Economic Analysis of Hydrogen Production by Gasification of Biomass." Final Report to U.S. Dept. of Energy, Contract DE-FC36-01GO11089, June 2003.

3.4 Other Biofuel Technology Options

A number of other routes exist to convert fermentable sugars, cellulosic biomass, waste greases, and vegetable oils to biofuels. Since each has specific niches where they may be appropriate, the potential benefits and drawbacks of each must be considered in the context of the potential site. Applications in Hawai'i present unique challenges for feedstock gathering and technology usage that make many alternatives unattractive based on their cost and level of technical maturity.

The other biofuel pathways that are currently receiving research and commercialization focus are FT liquids, direct hydrogenation of vegetable oils and greases, biomass pyrolysis, routes to convert biomass to fungible gasoline, and biobutanol production. Each is highlighted below, with a discussion for potential costs and suitability for usage in Hawai'i.

3.4.1 Fisher-Tropsch Liquids

As mentioned earlier, the FT liquids process consists of conversion of carbon containing feedstocks to syngas, with the syngas then cleaned and catalytically converted to liquid transportation fuels. A simplified schematic of the processes needed in a combined coal and biomass FT unit as developed by the US Department of Energy's National Energy Technology Laboratory[3] (NETL) is shown in Figure 3-6. The schematic includes equipment to capture and sequester CO_2, which may or may not be included in a biomass only design.

[3] US Department of Energy, National Energy Technology Laboratory, "Affordable, Low-Carbon Diesel Fuel from Domestic Coal and Biomass", DOE Report DOE/NETL-2009/1349, January 2009.

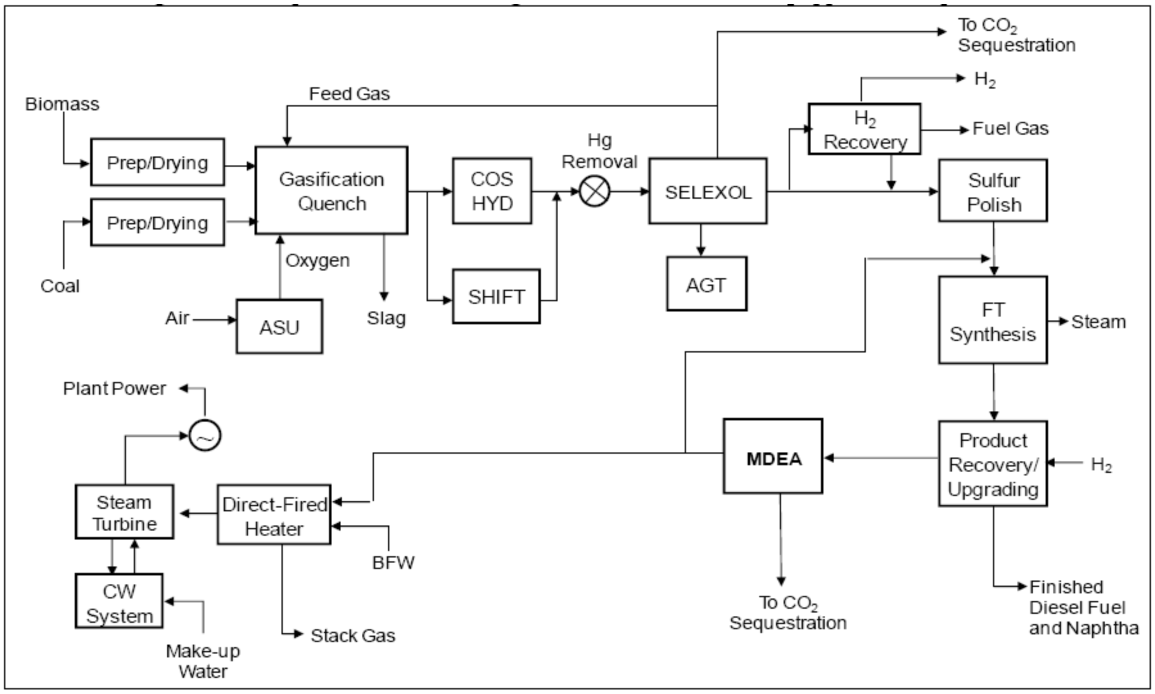

Figure 3-6. Coal and Biomass to FT Liquids Process Schematic[4]

To produce FT liquids from biomass, biomass is first prepared for gasification. This is done typically though sorting, grinding, and drying. Gasifiers appropriate for use on biomass, namely air-blown, atmospheric pressure, circulating fluidized beds, would likely be used. Gas cleaning consists of particulate removal, tar cracking, water-gas shift to obtain the H_2/CO ratio appropriate for the FT reactor, and potentially sulfur removal depending on the sulfur content of the feedstock. The cleaned syngas would then be sent through the FT unit, consisting of either iron or cobalt catalysts, at process conditions around 300ºF and 500 psi. Since production of FT liquids is a very exothermic reaction, FT reactor design is critical to removing the process heat and maintaining appropriate process conditions. The raw FT products are then condensed and separated into their constituent components. Further upgrading can either be performed on-site or at a separate facility based on the desired disposition of the products. Non-condensable gases are separated to remove the unreacted syngas, CO_2, and light hydrocarbons. Unreacted syngas is typically recycled back to the FT reactor to raise yields and improve process economics.

[4] Based on the feedstock used, some of the processes listed in this schematic may not be employed in a biomass only unit. For example, an Air Separation Unit (ASU) would be unnecessary if air-blown gasification is employed, certain sulfur conversion and removal units (COS Hydrolysis and Sulfur Polish) may not be needed if the sulfur content of the feedstock is low enough to not poison the FT catalyst, and hydrogen recovery/upgrading would not be employed if no upgrading is done on-site.

The FT products consist largely of diesel fuel, jet fuel, and low-octane naphtha (which can be used as a gasoline blending component or chemical feedstock). The diesel and jet fuels are of excellent quality and need little upgrading prior to being used in conventional distillate applications. The ratio of the three products (along with others including light gases and heavy waxes) is dependent on a number of factors, including reaction temperature, the H_2/CO ratio of the syngas, catalyst type, and reactor design. Other catalysts are available for producing other types of liquid fuels and chemicals such as mixed alcohols and methanol. The alcohols pathway is discussed in more detail during the cellulosic ethanol discussion, while the fungible fuel uses of methanol are discussed in Section 3.4.4.

Because the process to produce FT products is very complicated and typically requires some level of stabilization and upgrading of the final product, the capital and operating costs are very high. While knowledge of the technology has been around since the 1920's, commercialization has only occurred in locations where crude oil has been unavailable; oil prices have historically been too low to stimulate development of FT units. Due to the large amount of process equipment needed, there is a major economy of scale advantage to the development of large plants. This is why coal is considered as the main feedstock for FT processes. The low BTU and high moisture content of biomass relative to coal make it much more difficult to procure the amounts of biomass needed to build facilities similar to those based on coal. NETL projected that commercial BTL plants would be roughly one-tenth the size of CTL plants, with finished product costs over $6/gallon. Besides the economy of scale disadvantage, BTL plants also suffer from poor conversion rates and gasification difficulties relative to coal.

Both Sasol and Shell have commercially operating FT plants. Only Sasol has a commercial CTL plant, with natural gas to FT liquids performed in Malaysia and in Qatar. Only one small stand-alone BTL plant exists today: the 300 barrel per day Choren BTL plant in Germany, which began commercial production in 2008. Due to recent downturns in the price of oil from historically high levels, there have been few proposals to move forward with a 100 percent biomass to liquids process. Two projects have been proposed using Wisconsin biomass (NewPage and Flambeau River) and received DOE funding, but have not proceeded beyond the design phase. A more typical use of biomass in an FT plant is as a co-feedstock that would be fired in a small percentage at a CTL unit. Other companies such as Rentech and Syntroleum have developed pre-commercial FT processes, but the high capital costs and volatile finished product prices have prevented further development.

3.4.2 Renewable Diesel via Direct Hydrogenation

Besides the conventional esterification of fatty acids that is typically used for the production of biodiesel, vegetable oils and greases can also be converted to diesel fuel via direct hydrogenation. In this process, oils or fats are typically first pre-treated with acid, caustic, and/or water. The treated material is then sent to a hydrotreater where the treated oils and greases interact with hydrogen in the presence of a catalyst to remove oxygenates, impurities, and create molecules of similar structure to that of petroleum diesel.

Hydrotreating is a process common to the petroleum refining industry. The simplest design would be to use an existing refinery hydrotreater to act as the main process unit. In this configuration, the feedstock oils or greases would be pre-treated in a separate unit, and then combined with a petroleum diesel stream before entering the hydrotreater. Alternatively, a stand-alone hydrotreater could be designed, with the finished product blended with petroleum diesel. A schematic of these types of arrangements developed by UOP can be seen in Figure 3-7.

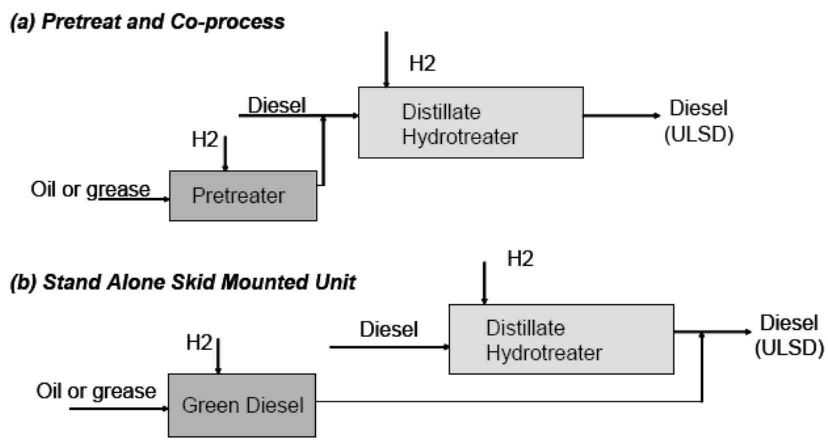

Figure 3-7. Refinery Integrated Renewable Diesel Options[5]

The co-processing option would only be available if existing petroleum refineries had the necessary equipment and capacity to process an oil or grease stream. Hawaii's two refineries have very limited hydrotreater capacity; according to the US DOE, most of the hydrotreating capacity (13,000 barrels per day) is for gasoline components, with the remainder (3,000 barrels per day) for residual fuel oil treating. No dedicated on-road diesel hydrotreating capacity is currently operational. Hydrotreating oils and greases also

[5] UOP, *Opportunities for Biorenewables in Oil Refineries*, US Department of Energy Report as part of award DE-FG36-05GO15085, 2005.

has the disadvantage of requiring high amounts of hydrogen, and potentially reducing the catalyst life of the hydrotreater unit.

If utilization of refinery hydrotreaters is unavailable, development of a stand-alone bio-oil treating unit would be necessary to produce renewable diesel in this fashion. A schematic developed by UOP for a stand-alone design can be seen in Figure 3-8.

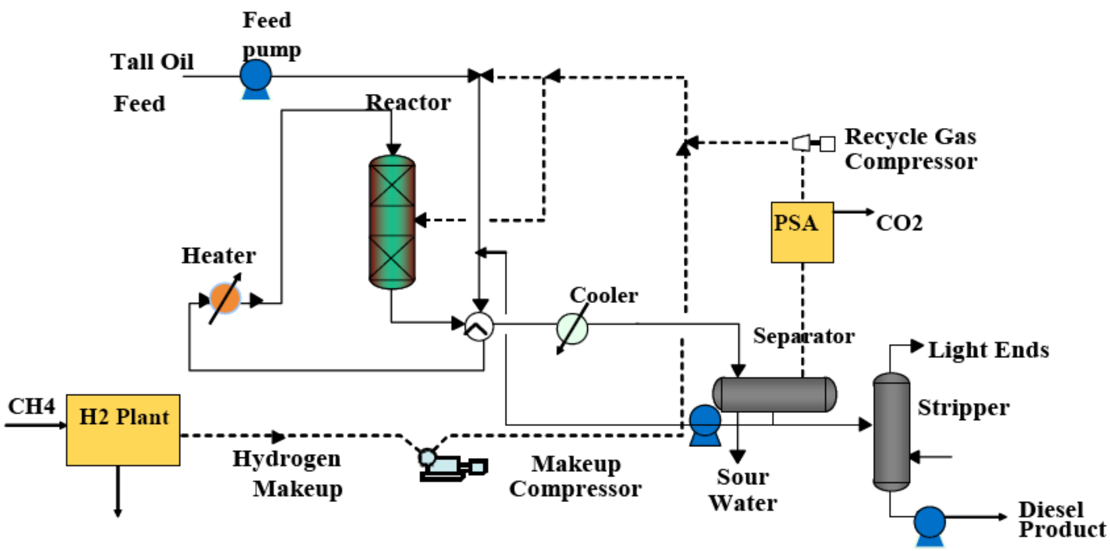

Figure 3-8. Stand-Alone Renewable Diesel Hydrotreating Schematic

Design and construction of a stand-alone renewable diesel hydrotreating unit would be much more complicated than integration with a refinery hydrotreater or development of a conventional esterification unit. Gas separation and reforming units would need to be constructed to produce the necessary hydrogen and separate gases produced in the hydrotreater. The location must be able to handle co-products of sour water and non-diesel hydrocarbons. Given the complexity and level of other inputs necessary to produce green diesel, it is unlikely that the cost would be attractive in Hawai'i relative to conventional biodiesel production routes.

A few companies are commercially developing refinery integrated oil and grease hydrotreating units today. Neste Oil, a Finnish refiner, has a small commercial plant operational at their Porvoo, Finland refinery, and is currently building plants in Singapore and Rotterdam. Petrobras, the main refiner in Brazil, has also developed an oil hydrotreating process that is being commercialized in South America. Finally, UOP is working with PNNL and NREL to commercialize an oil hydrotreating process in the US.

3.4.3 Pyrolysis Oils

Raw biomass can be heated indirectly in an oxygen free environment at temperatures lower than what is needed for gasification to produce pyrolysis oils. Under pyrolysis conditions, charcoal, gases, water, and pyrolysis oil are produced. The ratios vary depending on the conditions, but the yield of pyrolysis oil is typically in the 40 percent range. The oil produced is of very poor quality and not suitable for transportation use. Upgrading of the oil must be performed to remove water, acids, and oxygen components.

The development of a platform to commercialize pyrolysis oil technology is not a new concept. Efforts have been underway since the 1980s. While there have been limited niche successes, there has been no widespread commercialization as of yet. Commercialization of pyrolysis initially appeared to have an advantage over other cellulosic routes in the 1990s and earlier this decade, but it appears that the difficulty in using and marketing the pyrolysis oil has now led to the technology falling behind. With this in mind, it appears that significant breakthroughs in developing improved processes are needed to make pyrolysis oil more useable in transportation applications. Major disadvantages relative to other cellulosic methods include:

- Oil Quality: Pyrolysis oil quality issues such as low energy content, water, and high pH create issues that are not seen in other routes. Besides blending problems, pyrolysis oils will need to be stored in material that will not corrode due to the acidic character of the fuel.
- Oil Blending: Pyrolysis oil is a mix of various chemical constituents that will vary depending on the feedstock characteristics. This makes a heterogeneous mix that is not ideal from the standpoint of processing/upgrading pyrolysis oil to more pure marketable products compared with other cellulosic routes.

One major advantage of pyrolysis is that the technology offers a potentially attractive scale match for medium scale conversion systems (e.g., 50 to 250 tons/day) that could be deployed in a distributed strategy for storable liquid fuel production, or with fairly convenient transport of stored liquid product to a centralized processing/upgrading conversion facility. This can address some fundamental drawbacks with long-distance transport of typically bulky biomass feedstocks to large centralized biomass conversion facilities.

Distributed collection of bio-oils could be of particular interest in a location such as Hawai'i where moving large quantities of raw biomass feedstock to a central processing location is not feasible. A plant processing 120 tons/day of biomass could theoretically produce roughly 8,500 gallons/day (200 barrels/day) of raw pyrolysis oil.

This is equivalent to one tanker truck full, which could be easily transported to a central collection point for transport via barge to a processing facility. Small to medium scale pyrolysis oil conversion units are relatively simple pieces of equipment which could be skid mounted and easily scalable, unlike many biofuel technologies that produce fungible final products. Figure 3-9 below shows a process schematic for a process developed by Dynamotive. Besides the main reactor, cyclone, and quench system, little other process equipment is needed. The residual char could be burnt to provide on-site power and heat.

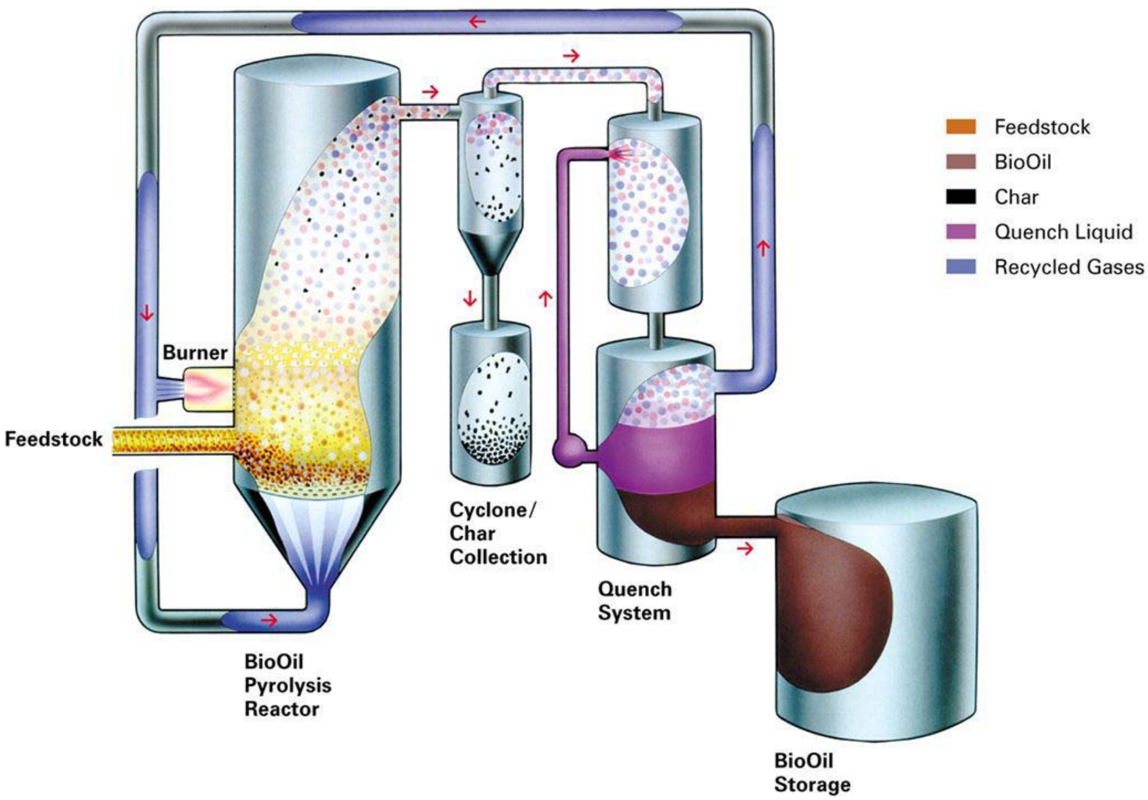

Figure 3-9. Dynamotive BioTherm™ Process Schematic

The poor quality of the bio-oil produced means that integration with a petroleum refiner or investment in upgrading equipment is necessary to make fungible fuels. This factor, combined with the fact that commercialization of pyrolysis oils to transportation fuels is behind other second generation biofuel routes, creates a competition issue that will require technical advances to overcome. Since upgrading on-site is expensive and impractical for small to medium scale units, partnering with a refinery or other type of central upgrading facility would be necessary to make pyrolysis oil practical. In Hawai'i, Tesoro has indicated interest in utilization of pyrolysis oils at their Kapolei refinery. Pyrolysis oils could be combined with crude oils, or fed directly into the hydrotreating or hydrocracking units. Removal of acidic compounds and water prior to charge to the refinery would likely be required to prevent corrosion. Utilization at Chevron's Barbers Point refinery could potentially also be an option; while it has limited hydrotreating and hydrocracking capacity, it does possess a catalytic cracking unit (used for upgrading fuel oils to gasoline) that could be suited for processing pyrolysis oils.

There are five main companies, and a number of smaller ones, pursuing commercialization of pyrolysis oils: Dynamotive, Ensyn, BTG, PyTec, and ROI. Dynamotive has been the strongest, most active company, with focus on applications using pyrolysis oil in industrial turbines or boilers. Typically, the focus of most firms has been on the use of pyrolysis oils for heat and power, not transportation fuels. However, greater interest in upgrading of pyrolysis oils has been witnessed. Ensyn and UOP recently partnered to create a joint venture, Envergent that specifically is working to commercialize pyrolysis oil production and upgrading units. Most of the companies are currently based in locations or have based their plants in areas with abundant and inexpensive feedstock. The relatively high cost of Hawai'ian biomass may make utilization of the pyrolysis pathway a challenge unless low cost upgrading options can be made a reality.

3.4.4 Biogasoline

There are a number of different pathways possible for the production of biogasoline from biomass, although none are actively in commercial demonstration. The first is catalytic cracking of pyrolysis oils or raw oils/greases in refinery process units. Similar to the renewable diesel option, this pathway requires the existence of very specific process equipment and could negatively impact the operation of the refinery units. The second option, which does have commercial experience and has been proposed in future coal to liquids designs, is utilization of methanol-to-gasoline (MTG) catalyst. In this process, biomass would be gasified to create syngas, similar to what is done for FT production. The syngas would be cleaned and sent to a methanol reactor to first produce methanol that would then feed the MTG section of the plant. Like FT liquids production, this is a complicated, high capital cost design that is better suited to coal feedstocks than natural gas. Finally, some novel processes are currently being explored such as Terrabon's MixAlco process, where biomass is treated by microorganisms to produce carboxylic acids, the acids converted to salts, the salts to ketones, the ketones to alcohols, and finally the alcohols to gasoline. None of these processes are appear to be economically promising enough or commercially applicable for the State of Hawai'i.

3.4.5 Biobutanol

Similar to how fermentable sugars can be converted to ethanol, sugars from biomass can also be converted to butanol via biological routes. The ABE (acetone, butanol, and ethanol) process is well known and understood. There are no large-scale ABE processes currently in-place due to the cost of the process, toxicity concerns of butanol, and fuel certification and transport issues. For these reasons, it is unlikely that biobutanol should be considered for application in Hawai'i.

3.4.6 Biological Conversion of Sugar to Conventional Fuels

Biological conversion technology is being developed that could convert sugar from crops such as sugarcane or sweet sorghum, into various chemicals and renewable fuels. For example, a Brazilian-based company, Amyris (and its U.S. subsidiary Amyris Fuels, LLC) is developing conversion technology that will use modified microorganisms to convert sugar into diesel, jet fuel, gasoline, and/or a variety of other products, such as lubricants or chemicals. Hawaii BioEnergy LLC is evaluating, and is optimistic about, the potential to use Amyris technology in Hawaii to produce conventional hydrocarbon-based fuels from sugar crops.

3.5 Projected Costs and Suitability in Hawai'i

There is a very wide range of costs possible for the biofuels reviewed above to due major variability in feedstock costs, technology advancement potential, upgrading needs, and co-product values. Potential cost ranges expected for the major biofuels routes described relative to conventional ethanol using a set of broad assumptions can be seen in Figure 3-10. More detailed analysis would be necessary to improve the accuracy of these estimates.

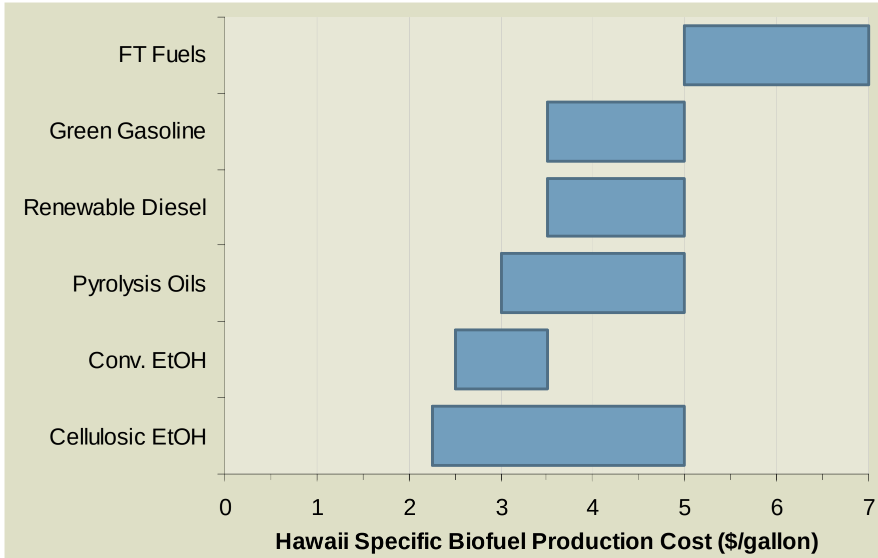

Figure 3-10. Advanced Biofuel Production Costs

In general, cellulosic ethanol production routes similar to those explored in greater detail elsewhere in the report have the greatest potential to produce transportation fuels at lower cost the conventional ethanol routes. Other production routes are currently too expensive, face too many technical hurdles, and/or have major unresolved issues regarding upgrading needed to make them suitable for on-road usage. For these reasons, cellulosic ethanol pathways should be the current major area of focus for alternative transportation fuels at this time. Monitoring of novel processes should be performed to determine their potential suitability as breakthroughs are achieved.

Based on the projected future prices of retail gasoline and diesel fuels and the development pathways of the alternative fuels presented in this section, it would not be expected that any alternative fuels besides conventional ethanol would be commercially competitive until at least 2015. Conventional fuel prices are projected by the US DOE to surpass $3.50/gallon (average US prices, 2007 dollars) at that date (see Figure 3-11 below); given the higher petroleum prices typically seen in Hawai'i and the potential cost improvements for the alternative fuel pathways shown in Figure 3-10, this date corresponds to the earliest potential timing that alternative fuels may likely be competitive with petroleum.

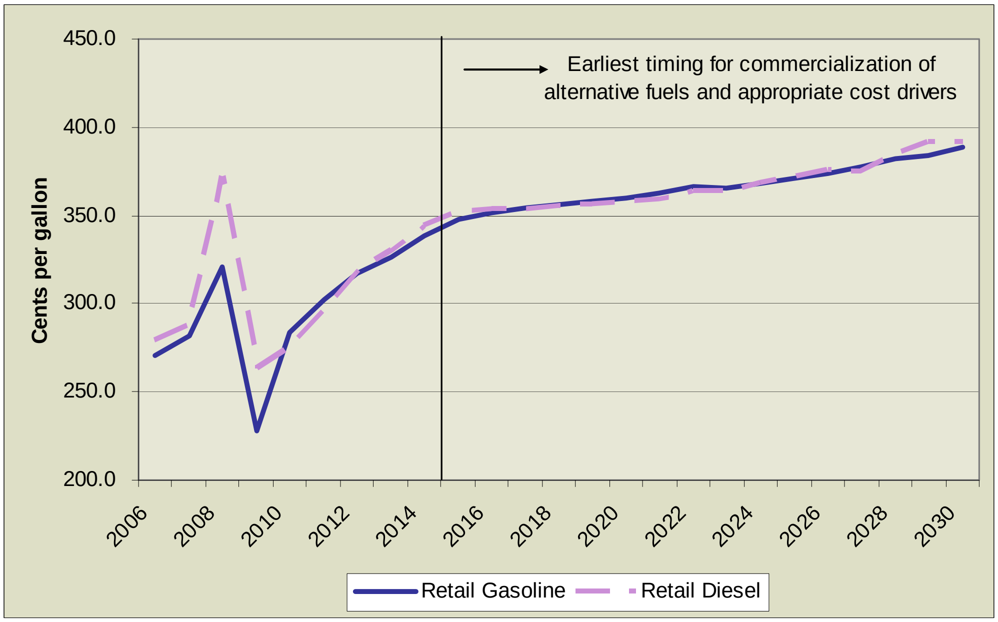

Figure 3-11. DOE Retail Gasoline and Diesel Projections

The alternative fuels discussed each have different promise with regards to cost reduction. Some, such as FT diesel and renewable diesel, have limited improvement potential due to the extensive catalyst research that has already been performed. The complexity and limited integration potential with petroleum refineries on Hawai'i will likely limit the ability of these routes to be a viable commercial alternative for biofuels. On the other hand, cellulosic ethanol, green gasoline, and pyrolysis oil research could yield breakthroughs that would make these routes competitive with fossil transportation fuels. Both green gasoline and pyrolysis oil research needs further investigation into catalyst improvements and upgrading options before they have the potential to be commercially viable. This is especially true for stand-alone units in locations without ready access to suitable upgrading equipment at petroleum refineries, such as Hawai'i. Thermochemical and biochemical production routes for cellulosic ethanol may have the greatest potential for lower cost biofuels. Different novel synthesis routes are being explored, with many claiming significant future cost improvements if research progresses as planned.

3.6 Additional Considerations for Biofuel Production in Hawai'i

Biomass is a regionally specific issue. This is true with regards to both the type and quantity of biomass available. There are several factors that can complicate the supply of biomass feedstock for a given process. The supply of biomass may not be consistent throughout the year due to seasonal variations. In addition it is often not practical or economical to transport biomass significant distances, or it may be difficult to recover enough resources in a given area to make a biomass conversion process economical. All of these forces put upward pressure on the economics of fuel derived from biomass.

3.6.1 Limitations on Transportation of Biomass

By its nature biomass is dispersed over a large geographic area. In addition, when biomass is in its raw unprocessed form it typically has a high moisture content and low energy density. These characteristics often make it unpractical and uneconomical to transport biomass significant distances. For mainland biomass conversion processes the maximum practical transportation distances often range from 75 to 100 miles.

Hawaii's geography, infrastructure and high fuel prices may also limit the radius which biomass could be practically and economically gathered. For example the limitations of existing highway infrastructure in places such as Kauai may prove an additional obstacle in making the biofuel production in Hawai'i economical. Of course in many cases the size of the islands in the Hawai'ian chain will limit the area that biomass can be gathered from. It is unlikely that it would be economical to transport biomass between islands in their raw and unprocessed forms.

3.6.2 Economies of Scale

Energy conversion processes generally benefit significantly from increased economies of scale. Large electrical generation stations or biofuel production facilities typically convert energy more efficiently and economically than similar facilities which are smaller in size. Due to constraints on resource availability in a given area, processes which use biomass as feedstock are not able to match the same economies of scale as processes which rely on fossil fuel. Thus for biomass facilities to be economically competitive they generally need to acquire feedstock's at a lower cost in order to compete with fossil fuels (in the absence of renewable energy incentives or regulations that penalize fossil fuels).

Since biofuel facilities that utilize cellulosic biomass are just entering the commercialization phase of development, one approach for gaining a perspective on economy-of-scale issues is to consider biomass power facilities that are fueled with cellulosic biomass (typically wood). Biomass power facilities are typically sized based on the resources which can be recovered economically in a given area, mainland standalone biomass generation facilities are typically no larger than 100 MW. Most often biomass facilities range from 30 to 50 MW in size. By comparison, newer coal fired power plants are rarely smaller than 600 MW. Table 3-9 below shows typical fuel usage for stand alone biomass power generation facilities.

Table 3-9. Daily Fuel Demand for Biomass Facilities.

Facility Size (MW)	Heat Rate (Btu/kWh)	Capacity Factor	Fuel (tons/day)	Trucks (load/day)
30	13,500	0.85	810	34
50	13,000	0.85	1300	54
100	12,300	0.85	2460	103

Notes:
Heating Value of 5,100 Btu per ton of biomass assumed with 40% moisture content.

Economies of scale are also an important factor in the biofuel conversion processes. Processing cost estimates for cellulosic ethanol production developed by the National Renewable Energy Laboratory (NREL) have typically been based on a scale of 2,000 tons of biomass per day. While it is likely that this scale of production facility may be difficult to achieve in Hawai'i, this cost estimate represents an industry target and reflects the future technical potential.

Based on the information presented above in Table 3-9 a 2,000 ton per day facility would roughly be equivalent to the demand created by an 80 MW biomass power generation facility. Figure 3-12 below show the land required to support a 2,000 ton per day cellulosic ethanol facility as a function of average yield of biomass per acre. The assumption was made that 2,000 tons would be needed each day and the facility would run 330 days each year. This would result in an annual demand of 660,000 tons of biomass.

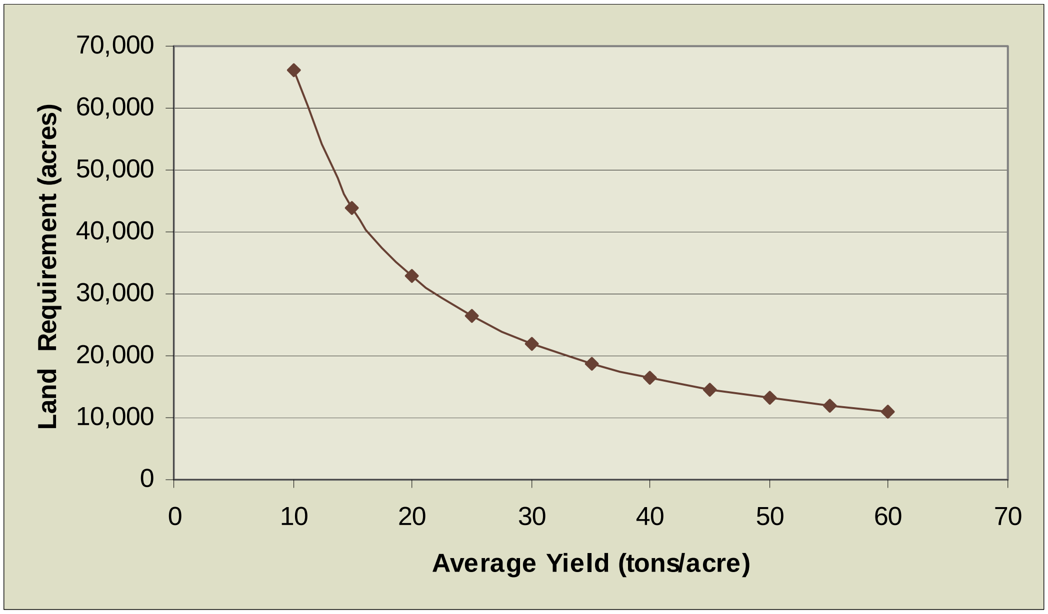

Figure 3-12. Land Requirements for a 2,000 Ton/Day Facility

Given that plantations in Hawai'i are likely to range from 5,000 to 10,000 acres and yields will likely range from 10 to 50 tons per acre depending on crop and soil types, there will be challenges associated with reaching the scale of a 2,000 ton per day cellulosic ethanol facility in Hawai'i. Thus, production facilities may need to be smaller than 2,000 tons per day or biomass would need to be brought from multiple locations. And as previously mentioned both of these options have the potential to negatively impact the economics of processing.

These constraints were taken into consideration in developing cost estimates for biofuels production in Hawai'i. For example, detailed cost estimates for cellulosic ethanol production recently updated by the National Renewable Energy Laboratory (NREL), showed cellulosic ethanol conversion costs in the range of $0.92 per gallon (on a levelized basis) by the year 2012 for large biochemical-based conversion facilities designed to process 2,200 tons per day of biomass feedstock (NREL, 2009; see Chapter 9 for projections from NREL regarding anticipated conversion costs for biochemical and thermochemical-based conversion systems). By comparison, in our base case analysis for Hawai'i, a conversion cost estimate of $1.36 per gallon was used. This estimate adjusts for economy-of-scale issues with the expectation that in Hawai'i, 500 to 800 tons per day may be a more likely scale for facilities based on acreage and transport constraints. (The conversion cost also factors in some cautiousness with respect to progress in reducing advanced biofuel conversion costs.) This potential economy-of-scale drawback for biofuel production in Hawaii can be offset by the advantage that

Hawaii facilities will have in marketing electricity co-produced with biofuel for distinctly higher electricity prices than "mainland" facilities.

Technologies such as pyrolysis may offer solutions to the issues of resource distribution and economies of scale related to biomass processing. Several medium-scale (250 to 700 ton per day) pyrolysis facilities may be useful in converting biomass into pyrolysis oil for processing at a centralized facility to transportation fuels. It would be easier to transport pyrolysis oil greater distances than raw biomass, and the liquid fuel is generally easier to store than solid biomass feedstocks. The technology used in converting raw biomass to pyrolysis oil is fairly straightforward and is generally well suited to small- to medium-scale applications.

Although most conversion technologies options are likely to benefit from economy-of-scale factors, not all will necessarily be affected to the same degree. For example, the cost of transesterfication technologies used for producing biodiesel from vegetable oils are generally not impacted as much by economy-of-scale issues as conversion processes for producing ethanol from cellulosic biomass, such as biochemical (e.g., enzymatic hydrolysis) or thermochemical (e.g. gasification) processes.

3.6.3 Distributed Processing & Centralized Refining

One potential solution to the competing forces of economies of scale and recoverable resources is to use some form of intermediate processing to increase the value or energy density of materials to be transported. This has the potential to make it more feasible to transport feedstocks greater distances to large centralized biorefineries. Pyrolysis which is discussed in Section 3.4.3 is one technology that may have promise for this application.

4.0 Biomass Residue Availability

Biomass residues encompass a wide variety of organic matter, ranging from wood waste, to agricultural residues, to other plant and human by-products. Waste from the production of primary marketable products is often an economically viable energy source. In Hawai'i, bagasse (sugarcane waste) has been a traditional biomass energy resource. However, the use of bagasse has decreased over the last three decades due to the declining sugar industry in Hawai'i.[6]

The potential supply of biomass residues available in Hawai'i was inventoried in the report "Biomass and Bioenergy Resource Assessment for the State of Hawai'i" prepared for DBEDT by the University of Hawai'i, Hawai'i Natural Energy Institute in 2002 (the report is available online at the following website -- www.hawaii.gov/dbedt/info/energy/publications/biomass-assessment.pdf). That report served as a baseline which has been updated in the following report. Unless noted, the information provided in the rest of this section has used a similar methodology to that used in the earlier 2002 report. Biomass sources reviewed in this study include domesticated livestock wastes, forest products residues, agricultural residues, and urban wastes. Agricultural wastes addressed include those generated from sugar cane, pineapple, and macadamia nut processing. The urban waste category was subdivided into four types: municipal sold waste, food waste, sewage sludge or biosolids, and waste greases.

4.1 Urban Waste

Hawai'i counties are facing an increasing growth in population resulting in increasing quantities of waste generated by people going about their daily lives. The overall goal of urban waste management is to collect, treat, and dispose of solid and liquid wastes generated by all population groups, even though some of those populations exist in rural areas. This waste can be exploited for biofuel production instead of being disposed of in a landfill. This section summarizes waste disposal inventories for municipal solid waste, landfill gas, sewage sludge, and fat/oil/grease (FOG).

[6] Anon. December 2006. A Catalog of Potential Sites for Renewable Energy in Hawaii. Produced for the State of Hawaii Department of Land and Natural Resources and the Department of Business, Economic Development, and Tourism by Global Energy Concepts, LLC in response to Act 95, Session Laws of Hawaii 2004.

4.1.1 Solid Waste

The trash generated by homes and businesses is called "solid waste," and the environmental department in each county in Hawai'i typically manages the collection, disposal, and recycling operations. Therefore, the assessment of solid waste is broken down by county in the following section.

City and County of Honolulu

Each year on O`ahu roughly 1.6 million tons of waste are generated. Approximately 500,000 tons of reusable waste, including green waste, tires and concrete, are recycled through a variety of programs. H-POWER, which is the City and County's waste-to-energy facility, processes 600,000 tons of waste annually. Another 200,000 tons are deposited into a private construction and demolition landfill. This leaves roughly 400,000 tons of waste per year that is brought to the City's Waimanalo Gulch Landfill, including 100,000 tons of ash per year generated by combustion of waste in the H-POWER facility.

Honolulu has an aggressive recycling program and about 30.8 percent of the island's waste stream is estimated to be recovered for beneficial reuse without going to either H-POWER or the landfill.[7] For example, any loads containing more than 10 percent yard trimmings are banned from the landfill and H-POWER. Green waste is recycled for the city by Hawai'ian Earth Products, which reprocesses clean yard trimmings, non-lead painted untreated wood waste, fruit & vegetable waste, and borate treated lumber into a variety of compost and mulch products. Hawai'ian Earth Products' two O`ahu facilities recycle approximately 85,000 tons of yard and tree trimmings annually. Hotels, restaurants, grocery stores, food courts, food manufacturers/processors and hospitals meeting specific size criteria are required to recycle food waste.[8] In the past year about 42,000 tons of food waste was diverted.[9] The bulk of this food waste goes to local hog farmers while the rest is redistributed for food donations in Hawai'i or shipped to the mainland, primarily for animal feed manufacturing (see Table 4-1).

[7] Boylan, Peter. February 3, 2008. Hawaii sending more waste to landfill. Honolulu Advertiser. (http://the.honoluluadvertiser.com/article/2008/Feb/03/ln/hawaii802030365.html)
[8] Revised Ordinances of Honolulu, Section 9, Article 3.5
[9] Unpublished data, City and County of Honolulu, Department of Environmental Services, Refuse Division, Recycling Office

Table 4-1. End Use of Food Waste Diversions in Honolulu.

Food Waste Use	Tons of diverted food waste
Local hog feed [a]	20,000 – 30,000
Exports [b]	8,000
Distributed donations of food [c]	5,000
Fats, Oil, and Grease [d]	4,000
Total [e]	42,000

Notes:

[a] No direct data available. Estimated based on the following assumptions: 1) ½ of hogs eat recycled food waste, 2) 10 pigs per sow, 3) dry matter makes up 25% of food waste. Source: Zaleski, H. Personal communication between Halina Zaleski (University of Hawai'i Swine Extension specialist) and Bret Harper.

[b] The majority of exported food waste goes to the mainland U.S. where more facilities exist for animal feed processing. Source: Unpublished data, City and County of Honolulu, Department of Environmental Services, Refuse Division, Recycling Office

[c] This includes food that is donated or no longer suitable for sale, but is still edible and fit for human consumption. Source: Hawai'i Food Bank - http://www.hawaiifoodbank.org/default.asp?doctype=sm&C_ID=246 and Aloha Harvest 2006 annual report.

[d] The majority of this waste is processed into biodiesel and glycerin products. Estimates of urban grease resources in the State of Hawai'i using factors from (1997) Measuring Recycling: A guide for state and local governments. United States Environmental Protection Agency, Solid Waste and Emergency Response. EPA530-R-97-011. (http://www.epa.gov/recycle.measure/docs/guide1.pdf)

[e] Does not include pre-consumer produce waste.

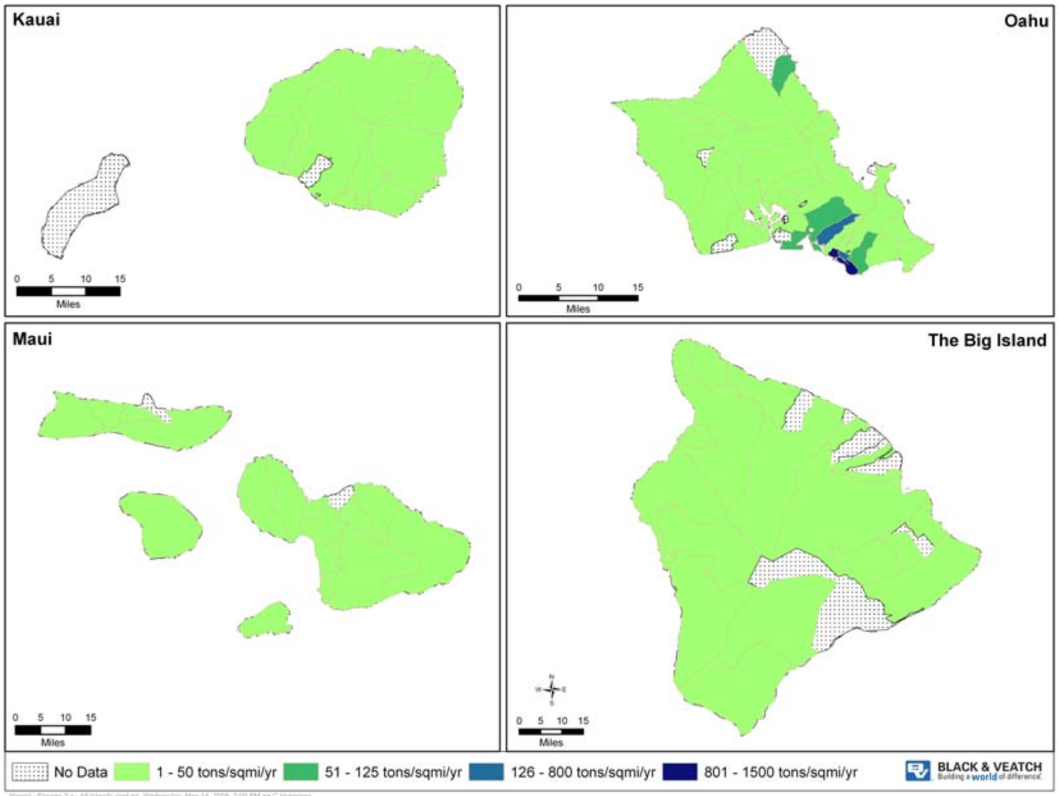

Figure 4-1. Hawai'i Food Waste.

In 2006, the activities of the population in the City & County of Honolulu (Honolulu) generated approximately 940,000 tons[10] of municipal solid waste.[11] Currently, all municipal solid waste generated in Honolulu is transported to either the H-POWER waste-to-energy facility or Waimanalo Gulch landfill. The typical waste streams of these sold waste facilities are very different as the landfill receives primarily materials which cannot be processed at H-POWER. The composition of Oahu's municipal solid waste stream is shown in Table 4-2. It is important to note that this annual waste estimate represents only the amount of material for both the waste-to-energy and municipal landfill waste facility. Approximately 20 percent of the waste destined for energy recovery at H-POWER is rerouted and ultimately disposed of at the Waimanalo Gulch Landfill due to H-POWER closures throughout the year. This estimate does not include the ash or residue material that is produced as a result of waste

[10] R.W. Beck. April 2007. 2006 Waste Characterization Study.

[11] For the purposes of this report the term "municipal solid waste", does not include C&D, diverted (recycled), or sewage sludge waste.

processing and combustion at H-POWER. As of July 2007, the landfill is utilizing 101 acres of the 200-acre property and only engages the remaining usable acreage as needed. Despite this room for growth, the immediate future of the only municipal landfill in Honolulu is in question, and the city is actively looking at alternatives including shipping the waste to the mainland, building another waste-to-energy facility, and/or installing an advanced plasma arc waste gasification system.[12] Although the majority of urban biomass is already burned at H-POWER, the remaining organic waste may represent an excellent opportunity as a bio-fuel feedstock.

Table 4-2. Waste Composition Summary by Solid Waste Facility - 2006.

	H-POWER		Waimanalo Gulch Landfill		Overall Aggregate	
Material	**Mean %**	**Annual Weight (tons)**	**Mean %**	**Annual Weight (tons)**	**Mean %**	**Annual Weight (tons)**
Paper	36.7	277,570	4.3	7,864	30.2	284,082
Green Waste	10.1	76,048	3.4	6,270	8.7	82,041
Wood	3.0	22,363	10.7	19,489	4.5	42,273
Other Organics *	24.1	181,937	27.6	50,788	24.8	232,874
Other Waste**	26.2	198,403	54.1	99,455	31.8	298,917
TOTAL	**100**	**756,321**	**100**	**183,866**	**100**	**940,187**

Source: R.W. Beck. April 2007. 2006 Waste Characterization Study for the City and County of Honolulu.

Notes:

* May includes food, textiles, carpet, tires, and sewage sludge.

** Includes plastics, metals, glass, inorganics, HHW and other inorganic waste.

Various tipping fees are associated with refuse disposal. H-POWER and the Waimanalo Gulch Landfill currently have a common tipping fee of $91 for every ton of trash commercial haulers dump in either site.[13] Such "tipping fees" subsidize free city trash collection from homes, Honolulu's recycling programs, and operations at the Office of Solid Waste Management within the State Department of Health. Green waste is recycled for the city by a private company with an associated commercial tipping fee of

[12] Advertiser Staff. 2008. Decisions pending on Hawaii rubbish options. Honolulu Advertiser, (http://www.honoluluadvertiser.com/apps/pbcs.dll/article?AID=/20080109/NEWS04/801090390/1008/NEWS04)

[13] Brannon, Johnny. May 1, 2007. Shipment of isle garbage hit snag. Honolulu Advertiser.

$37 - $42 per ton of green waste, $25 per ton of ground chips, and $50 - $80 per ton of untreated wood. Tipping fees for C&D waste at the PVT Landfill begin at $30 per ton for large semi trailer loads. Rates for pickup truck or van loads are higher at $72 per ton. Special charges apply for loads containing asbestos, petroleum contaminated soil, concrete, lead acid batteries tires, mattresses, and carpet. There is no charge to County residents who self-haul MSW or green waste to the Landfill.

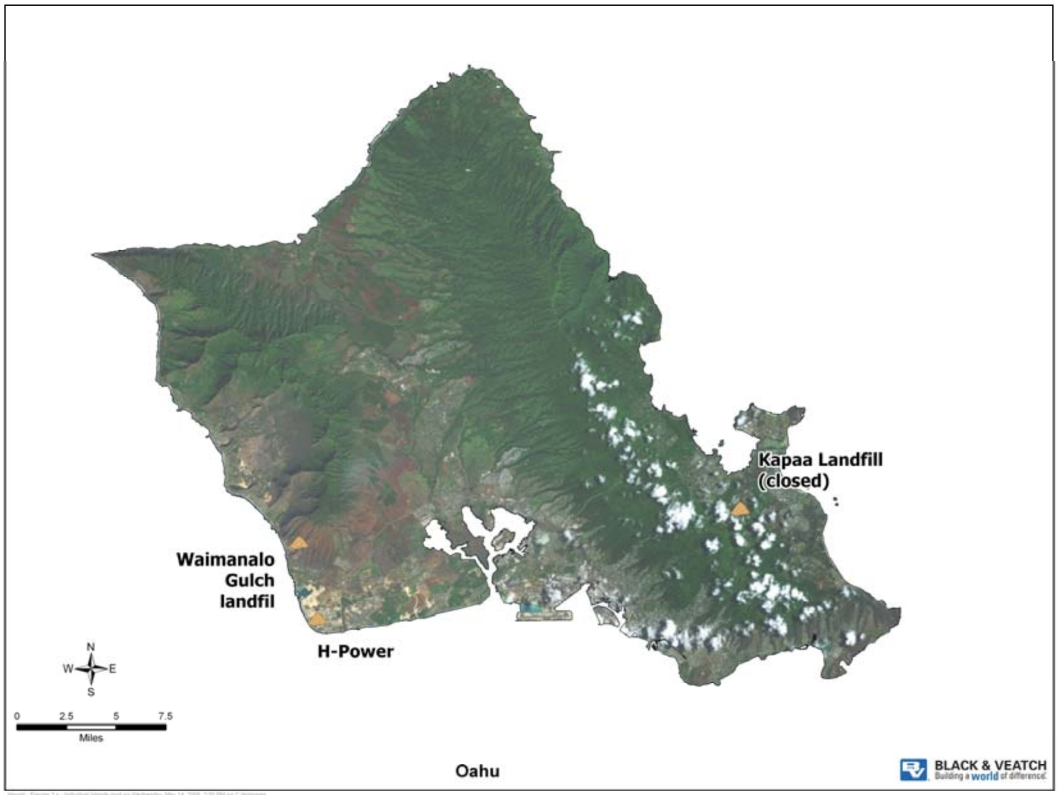

Figure 4-2. O`ahu Landfills and Waste-to-Energy Facility.

County of Maui

Each year in Maui County roughly 400 thousand tons of wastes are generated. Approximately 80,000 tons of reusable waste, including green waste, tires and concrete are recycled through a variety of programs. Another 50,000 tons are deposited into a private construction and demolition landfill. This leaves roughly 270,000 tons a year that is brought to the County's four municipal landfills.[14]

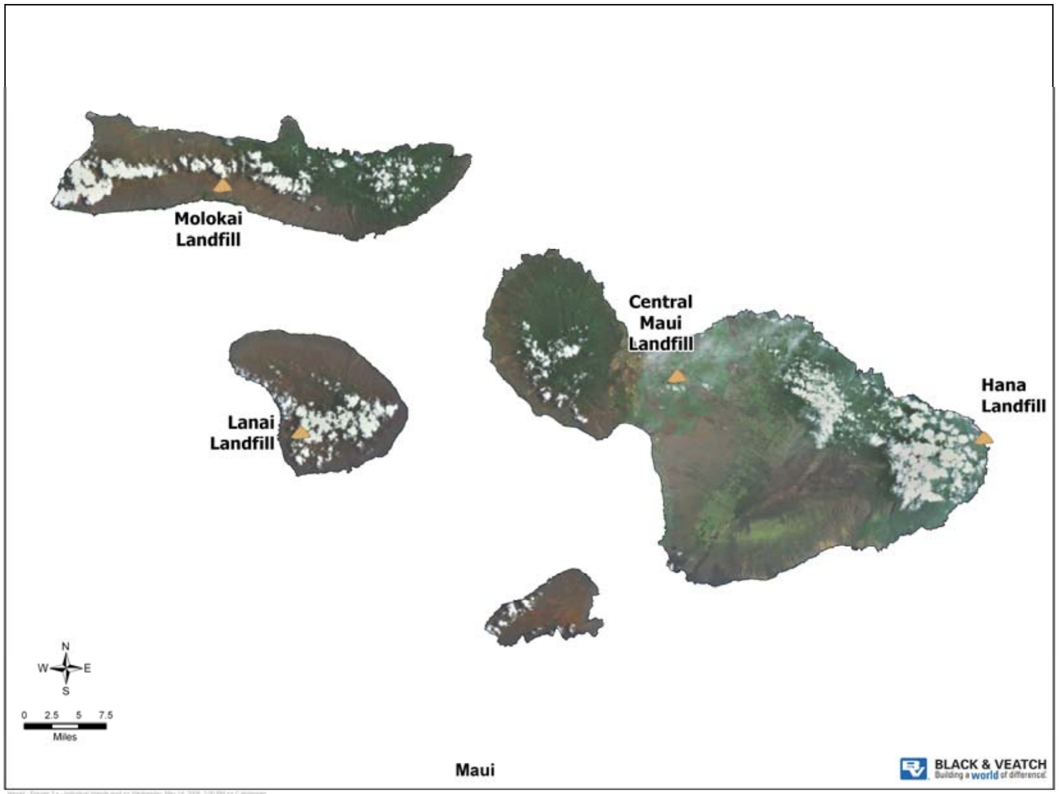

Figure 4-3. Maui Solid Waste.

Maui has a recycling program and about 30 percent of the county's waste stream was estimated to be recovered for beneficial reuse without going into a municipal landfill in 2006.[15] For example, green waste diversion has grown dramatically in the last 5 years and is recycled for the county by Maui EKO and Maui Earth. About 30,000 tons of yard and tree trimmings are composted with sewage sludge annually. A facility on Molokai composts approximately 3,000 tons of green waste per year.

In 2007, the activities of the population in the County of Maui generated nearly 280,000 tons of municipal solid waste.[16] Currently, all municipal solid waste generated on Maui goes to either the Central Maui Landfill (600 tons per day) or the Hana Landfill

[14] A-Mehr, Inc. September 20, 2007. Landfill Capacity. Maui Solid Waste Advisory Committee's Integrated Solid Waste Management Plan.
[15] Anon. December 2006. Report to the Twenty-Fourth Legislature, State of Hawaii, 2007. State of Hawaii, Department of Health, Office of Solid Waste Management.

(4 tons per day). All municipal solid waste generated on Moloka`i and Lana`i go to their local landfills – 18 and 13 tons per day, respectively. Although a waste composition study is currently in progress, Maui's solid waste division estimates the composition of Maui's municipal solid waste stream to be 42 percent organic.[17] As of September 2007, the Central Maui Landfill has three years of remaining life in the currently permitted phase. An additional 16 years of life will be added after expansion into the adjacent quarry area. Given the tiny input at the Hana Landfill, the permitted capacity should last far into the future. The private C&D landfill has an estimated 6 years of permitted life, with an uncertain future. Eight years of permitted life exist at the Moloka`i Landfill, with an additional 22 years of additional capacity within the existing area. The Lana`i landfill has an estimated 13 years of permitted life, with an additional 4 years available with a modest vertical expansion of the maximum height. Despite the fact that all County-owned sites have an estimated 15 years status quo projected tonnage life available, the future closure of the private C&D Landfill my represent an opportunity for diverting biomass feedstock from the stressed Central Maui Landfill.[18] There is no charge to County residents who self-haul MSW or green waste to the landfill.

County of Hawai'i

Each year on the Big Island roughly 300 thousand tons of waste is generated. Approximately 80,000 tons of reusable waste, including green waste, tires and concrete, are recycled through a variety of programs. This leaves roughly 220,000 tons per year that are brought to the County's two municipal landfills, including nearly 18,000 tons of construction and demolition waste and 2,000 tons of sewage sludge.[19]

[16] For the purposes of this report, the term "municipal solid waste" does not include C&D, recycled or sewage sludge waste.
[17] Includes food waste, large yard waste, leaves and grass, land clearing debris, disposable diapers, and wood. Does not include paper, rubber, or textiles.
[18] A-Mehr, Inc. September 20, 2007. Landfill Capacity. Maui Solid Waste Advisory Committee's Integrated Solid Waste Management Plan.
[19] Anon. December 2006. Report to the Twenty-Fourth Legislature, State of Hawaii, 2007. Prepared by: State of Hawaii, Department of Health, Office of Solid Waste Management.

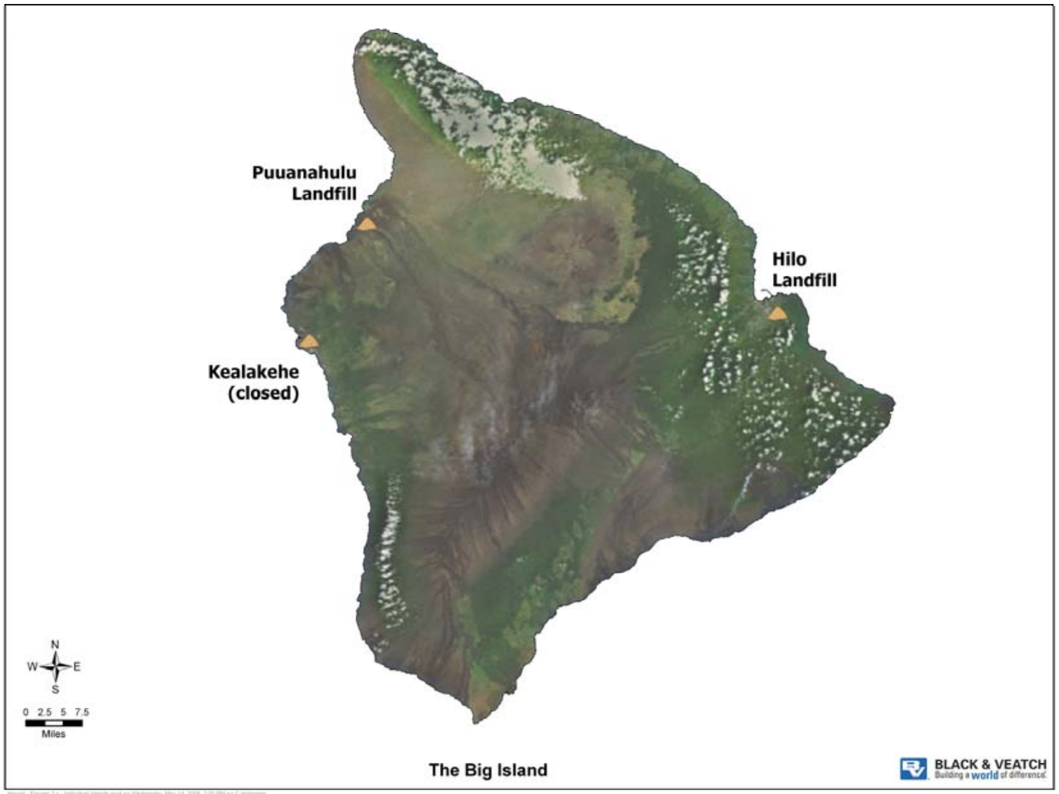

Figure 4-4. Big Island Landfill Locations.

The Big Island has a recycling program and about 25.8 percent of the county's waste stream is estimated to be recovered for beneficial reuse without going into a municipal landfill. For example, green waste diversion is recycled for the county by EKO Compost, which recycles palm fronds, tree and hedge cuttings, grass clippings, untreated and unpainted wood pallets, and small logs.

In 2006, the activities of the population of the Big Island generated approximately 200,000 tons of municipal solid waste.[20] Currently, all municipal solid waste generated on the Big Island goes to either the Hilo Landfill or Kona landfill at Pu`uanahulu. Although a new waste composition study is currently in progress, the Big Island's solid waste management plan from 2002 estimates the composition of the landfill solid waste stream to be about 43 percent organic.[21] The Hilo Landfill is slated to close in August 2010. The county council is awaiting a final offer from a private mainland firm to build a waste-to-energy incinerator to replace Hilo's landfill, but alternatives include hauling

[20] For the purposes of this report, the term "municipal solid waste" does not include C&D, recycled or sewage sludge waste.

trash to the Kona landfill, opening a new landfill in Hilo, or shipping the trash off the island. The imminent closure of the Hilo Landfill may represent an opportunity for diverting biomass feedstock to energy applications from the stressed Kona Landfill.[22]

Table 4-3. Composition of the Material Entering the South Hilo Landfill Only[*].

Material	Mean %	Annual Weight (tons)
Paper	23.5	15,724
Green Waste	5.4	3,621
Wood	12.1	8,109
Other Organics [**]	25	16,730
Other Waste	34	22,841
TOTAL*	**100**	**67,025**

Source: Anon. 2002. Final Draft Revision 1, November 15, 2002, Addendum to the Integrated Solid Waste management Plan for the County of Hawai'i. Harding ESE, Aiea, Hawai'i.

Notes:

[*] South Hilo Landfill only receives about a third of the county's waste. Another 2/3 goes to the Kona Landfill.

[**] May includes food, textiles, and carpet.

Various tipping fees are associated with refuse disposal and these fees are expected to increase in the future, possibly radically when the Hilo landfill closes. According to the Final EIS, the capital and operating costs of a new Hilo Landfill with the improvements to the County Wastewater Treatment facility necessary to handle treatment of the leachate runoff from the dump would be $83.89 per ton. This is higher than the $50 per ton currently paid to the Waste Management for operation of the existing Hilo Landfill. The $50 figure, however, does not include leachate treatment nor does it include contributions to post closure expenses. Together these items are projected to cost $36.78.[23] Leachate runoff and costs could be reduced by building a "bioreactor" type landfill which is aerated, kept moist, and hosts garbage-decomposing microorganisms. There is no charge to County residents who self-haul MSW or green waste to the Landfill.

[21] Includes food waste, large yard waste, leaves and grass, land clearing debris, disposable diapers, and wood. Does not include paper, rubber, or textiles.

[22] Quirk, Jim. December 9, 2007. What will the county do in '08? Hawaii Tribune Herald.

[23] Walden, Andrew. December 8, 2005. Big Island Garbage Kept off Council Agenda. Hawaii Reporter, special from Hawaii Free Press.

County of Kaua'i

Each year on Kaua`i roughly 120,000 tons of wastes are generated. Approximately 30,000 tons of reusable waste, including green waste, tires and concrete are recycled through a variety of programs. This leaves roughly 90,000 tons a year that is brought to the County's only landfill, including 4,000 tons of mixed commercial and demolition waste and 1,000 tons of sewage sludge, grit, and sand.[24]

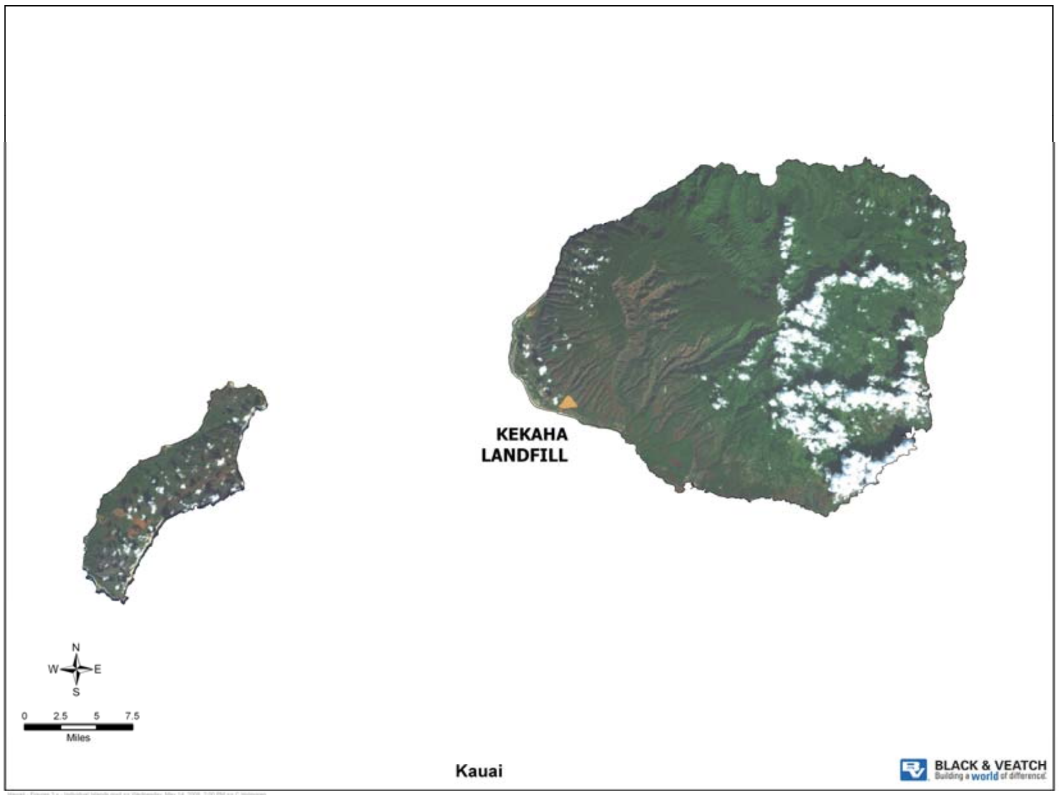

Figure 4-5. Kaua`i Landfill Location.

Kaua`i has a recycling program and about 25 percent of the county's waste stream is estimated to be recovered for beneficial reuse without going into a municipal landfill. For example, residents can dispose of green waste free of charge at any of the four transfer stations or at the Landfill. In FY 2005, approximately 10,535 tons of green waste was collected and shredded by County operations. During 2005, an estimated 3,000 tons of commercial green wastes were composted by two permitted green waste composters in the County.

[24] Anon. October 2007. Draft Integrated Solid Waste Management Plan, County of Kaua`i, Department of Public Works – Solid Waste Division. Prepared by: R W Beck.

In 2005, the activities of the population in the County of Kaua`i generated approximately 84,000 tons of municipal solid waste.[25] Currently, all municipal solid waste generated on Kaua`i goes to the Kekaha Landfill (200 tons per day). The 2007 waste composition study, prepared by R W Beck, estimates the composition of Kaua`i landfill waste stream to be approximately 29 percent organic.[26]

Table 4-4. Summary of 2007 Solid Waste Characterization Conducted for Kaua`i County.

Material	% Residential Waste Stream	% of Commercial Waste Stream
Paper	33.8	38.5
Green Waste	8.0	5.5
Wood	2.0	4.7
Food Waste	15.7	13.5
Textiles and Leathers	3.2	4.6
Diapers	2.9	1.7
Rubber	0.2	0.3
Other Organics	0.8	0.7
Other Waste*	33.4	30.5
TOTAL	**100**	**100**

Source: Anon. October 2007. Draft Integrated Solid Waste Management Plan, County of Kaua`i, Department of Public Works – Solid Waste Division. Prepared by: R W Beck.

Notes:

* Includes plastics, metals, glass, inorganics, HHW and other inorganic waste.

The current tipping fee paid by the private haulers and other commercial vehicles at the landfill is shown in Table 4-5. There is no charge to county residents who self-haul MSW or green waste to the landfill.

[25] For the purposes of this report, the term "municipal solid waste" does not include C&D, recycled or sewage sludge waste.

[26] Includes food waste, large yard waste, leaves and grass, land clearing debris, disposable diapers, and wood. Does not include paper, rubber, or textiles.

Table 4-5. Kaua'i Commercial Tipping Fees per Ton.

Type of Waste	Dollar per Ton
MSW and green wastes (except special wastes)*	$56.00
Asbestos-containing materials	$70.00
Dead animals	$56.00

Source: Anon. October 2007. Draft Integrated Solid Waste Management Plan, County of Kaua`i, Department of Public Works – Solid Waste Division. Prepared by: R W Beck.

Notes:

* There is no charge to County residents who self-haul MSW or green waste to the Landfill.

4.1.2 Non-Solid Waste

Non-solid waste refers to a gas and sludge produced by the biological breakdown of organic matter in the absence of oxygen. Biogas is comprised primarily of methane (50 to 75 percent) and carbon dioxide (25 to 50 percent). Landfills and wastewater treatment plants are the major sources of biogas in Hawai`i.

Landfill Gas

Compressed solid waste in landfills creates biogas, this trapped biogas can be tapped with wells and piped to a small processing plant and either burned to generate electricity, cleaned and used directly in compressed natural gas vehicles, or reformed to create hydrogen. The technology to generate electricity is well established and has been used in the past at the Kapa`a Landfill in Kailua, O`ahu; however, the amount of biogas production from a landfill is well known to drop exponentially over time once the landfill stops receiving waste. Developers are exploring landfill gas utilization at the Kapa`a landfill in Kailua (on O`ahu), at Waena in Central Maui and at Pu`uanahulu in West Hawai'i on the Big Island.[27]

In August 2005, Waste Management began full-time operation of a landfill gas collection and control system at the Waimanalo Gulch Landfill on O`ahu. This gas management system allows for the combustion of landfill gas in a controlled environment, eliminating odors and destroying a potent greenhouse gas. Today there are 36 gas extraction wells throughout the site. A landfill gas to energy project will be implemented sometime in the near future to convert landfill gas to electricity. Currently Waste Management utilizes an enclosed flare at the site to burn off more than 400 cubic

[27] HECO. Landfill Gas. Hawaii's Energy Future, Renewable Energy Sources. (http://www.hawaiisenergyfuture.com/Articles/Landfill_Gas.html)

feet per minute of methane gas from the landfill at approximately 1,800 degrees Fahrenheit.[28]

The City and County of Honolulu has completed work necessary to solicit contractors for bioenergy production at the Kapa`a landfill. The landfill produced about 3 MW from 1989 to 2002, until turbine problems forced closure. The gas analysis confirmed that the methane BTU content of the gas sampled was consistent with landfills of its age, and that sulfur and siloxane values were relatively low.[29]

The Kona landfill at Pu`uanahulu on the Big Island remains open, with 900,000 tons of waste in place and may produce about 300,000 cubic feet of biogas per day.[30]

There is only one viable landfill gas project on Kauai, located at the Kekaha landfill. (There is one smaller landfill, but it is not suitable for development.) Black & Veatch estimated the energy production of this project after the planned landfill closure in 2009. In this case, the maximum gas flow is approximately 465 cubic feet per minute and occurs in 2009.[31]

Sewage Sludge

Wastewater is treated at military, private, and public facilities in Hawai'i as shown in Table 4-6.[32] Most of these facilities, however, are small and do not have dewatering capability. Standard practice is for these smaller wastewater plants to truck their sludge to larger public facilities for dewatering, which has the effect of consolidating potential sources of sewage sludge.

[28] Anon. July 2007. Waste Management Report to the community: Landfill Operations and Community Involvement. Prepared by Waste Management.
[29] Anon. December 2005. Progress Report to the Governor and the Legislature of the State of Hawaii Regarding State Support for Achieving Hawaii's Renewable Portfolio Standards. By the State of Hawaii Department of Business, Economic Development, and Tourism.
[30] EPA. Landfill Methane Outreach Program. (http://www.epa.gov/lmop/)
[31] Anon. 2007. Unpublished report from the Kauai Island Utility Cooperative's Final Report 2010 Landfill Gas. Prepared by Black & Veatch.
[32] Anon. Listing of waste water treatment facilities, capacities, and aggregate sludge generation by island in Hawaii in 2006. Unpublished data from the Hawai`i Department of Health, Waste Water Branch Chief, Marshall Lum.

Table 4-6. Summary of Number, Location, and Ownership of Wastewater Treatment Plants and Sludge Production and Amount Diverted from Land-Filling in Hawai’i.

Island	Public	Federal	Private	Tons Produced	Tons Diverted
Hawai`i	5		32	183	0
Kaua`i	5	1	28	246	0
Maui	3		21	3,352	3,352
Moloka`i / Lana`i	2		11	n.a.*	n.a.*
O`ahu	8	3	51	16,576	891
Total	**23**	**4**	**143**	**20.357**	**3,462**

Source: Turn et al. 2002. Biomass and bioenergy resource assessment, State of Hawai’i. Hawai’i Natural Energy Institute, School of Ocean and Earth Sciences and Technology, University of Hawai’i.

Notes:

* Data not available.

The largest wastewater facilities have activated sludge treatment, which use microorganisms in secondary treatment. This process produces biogas that is 60 to 70 percent methane. At the Kailua Wastewater treatment plant about 20 percent of this methane is burned to maintain the optimum temperature for the microorganisms, while the rest is flared for ease of disposal. This biogas has the potential to be reformed into hydrogen fuel.

Table 4-7. Summary of Treatment Process of Wastewater Treatment Plants and 2006 Sludge Production for Major Plants.

Plant	Treatment	2006 Sludge (tons) [d]
Ahuimanu	Screen [a]	N/A
Ele`ele	Activated sludge	N/A
Hilo	Bio-tower	N/A
Honolulu	Primary [b]	7,668
Kapehu	Rock Media, secondary	N/A
Kealakehe	Oxidation pond	N/A
Kihei	Activated sludge	6,633
Kulaimano	Activated sludge	N/A
Lahaina	Activated sludge	7,539
Lihue	Bio-tower	N/A
Papaikou	Activated sludge	N/A
Sand Island	Primary [c]	N/A
Wahiawa	Activated sludge	828
Waianae	Bio-tower	N/A
Wailua	Activated sludge	N/A
Wailuku	Activated sludge	10,567
Waimanalo	Activated sludge	57
Waimea	Activated sludge	N/A

Source: Listing of waste water treatment facilities, capacities, and aggregate sludge generation by island in Hawai'i in 2006. Unpublished data from the Hawai'i Department of Health, Waste Water Branch Chief, Marshall Lum.

Notes:

[a] Ahuimanu has been converted to a pretreatment facility and pump station. It no longer treats wastewater but sends it to the Kailua Wastewater Treatment Plant for further processing after it is screened.

[b] The Honolulu plant has about a third of its flow treated to tertiary levels for reuse and the rest is still primary treated.

[c] Sand Island is considered as an advanced primary treatment plant.

[d] Preliminary data for 2006. Note, the county of Kauai and Big Island did not submit data to the Hawai'i State Department of Health.

At present, sludge reuse has been accomplished by composting biosolids with green waste on Maui and O`ahu. Maui County's program diverts all sewage biosolids to compost production under contract to Maui EKO Systems, Inc. The Navy established a biosolids treatment facility at Barbers Point that composts sludge from the Fort Kamehameha and Schofield Barracks WWTP's and the Honolulu WWTP operated by the City and County of Honolulu. In 1999, 891 tons (dry basis) of the City and County's biosolids were composted with green waste. This value was increased to 10 tons (dry basis) per day in 2002 resulting in an annual diversion of 3,650 tons of sludge from the landfill.[33]

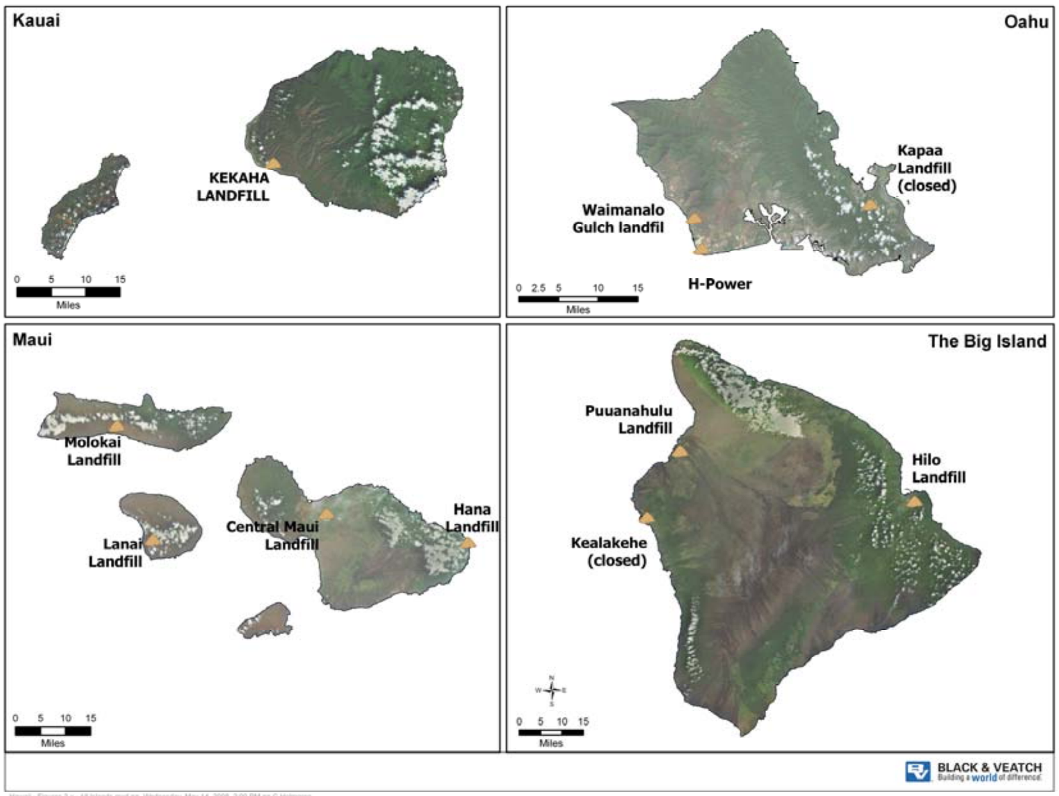

Figure 4-6. Major Wastewater Treatment Plants on Hawai'ian Islands.

The City and County of Honolulu also recently announced a new sludge reuse project to be located at the Sand Island WWTP. A contract has been awarded to Syangro-WWT Inc. of Millersville, Maryland to design, build, and operate an anaerobic sludge digester to produce a stabilized, pelleted soil conditioner. A gas collection system and hydrogen sulfide removal unit will be part of the facility. The new facility is designed to divert all of the sludge from the Sand Island WWTP from current landfill disposal.[34]

The Sand Island Wastewater Treatment Plant is a primary treatment facility serving metropolitan Honolulu (the largest WWTP facility in the State of Hawai'i). The

[33] Anon. Listing of waste water treatment facilities, capacities, and aggregate sludge generation by island in Hawaii in 1999. Unpublished data from the Hawai`i Department of Health, Waste Water Branch Chief, Marshall Lum.
[34] Gonser. J. 2003. Sewage conversion plant planned. Honolulu Advertiser, February 18th, 2003.

plant is undergoing major system modification due to capacity expansion and waiver of secondary treatment.[35]

Fat, Oil, and Grease

Fat, Oil, and Grease (FOG) are largely the result of cooking wastes. This resource can be separated into two broad categories: yellow grease, which is diverted before being disposed down the drain, and brown or trap grease, which is captured after being disposed down the drain.

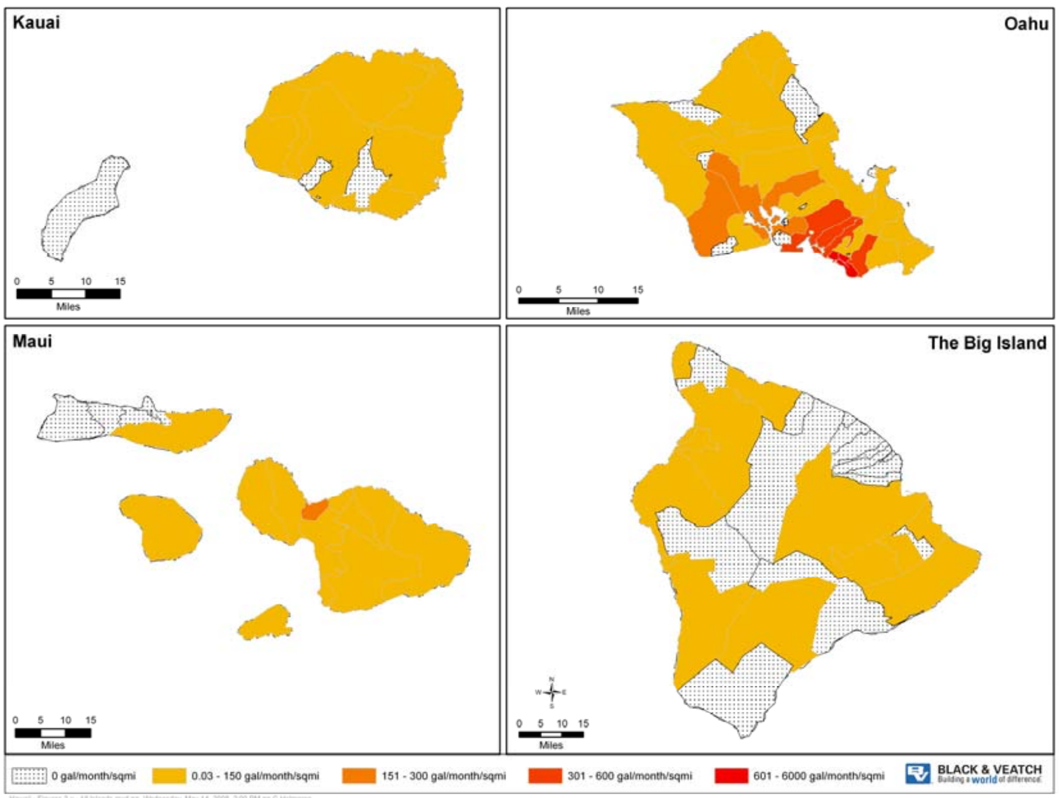

Figure 4-7. Fats, Oil, and Grease.

Large hotel and restaurants are required to collect and recycle their FOG. The FOG is normally collected by a private recycler who processes it into products such as animal feed, fuel, and tallow.

[35] According to Section 301(h) of the 1981 Municipal Wastewater Treatment construction Grants Program.

Table 4-8. Estimates of Urban Grease Resources in the State of Hawai'i Using Factors from EPA (1997).

County	Defacto Population	Grease (tons/year)		
		Yellow	Trap/Brown	Total
Honolulu	1,000,000	4,000	6,000	**10,000**
Hawai`i	200,000	900	1,000	**1,900**
Kaua`i	90,000	400	600	**1,000**
Maui	200,000	900	1,000	**1,900***
Total	**1,490,000**	**6,200**	**8,600**	**14,800**

Source: Anon. 1997. Measuring Recycling: A guide for state and local governments. United States Environmental Protection Agency, Solid Waste and Emergency Response. EPA530-R-97-011. (http://www.epa.gov/recycle.measure/docs/guide1.pdf)

Notes:

* The majority of this grease is probably already being utilized by Pacific Biodiesel

Grease traps are baffled tanks installed on drain lines of food preparation and dishwashing sinks to prevent it from entering the sewer line. If too much FOG enters the sewer system, it can accumulate on the walls of pipes and block sewer lines. These tanks are designed to reduce the velocity of the flow allowing the FOG to float to the top and become trapped by the baffles. Heavier sediment eventually collects on the bottom of the tank as well. The efficiency of the trap decreases as more FOG accumulates and must be emptied on a regular schedule, normally when the FOG accumulation fill about 25 percent of the trap capacity. Private pumper trucks collect the FOG.

Reclaimed FOG has a number of uses in the islands. For example, Island Commodities sells reprocessed FOG as fuel to Young Drycleaners, which uses it in a boiler. Hawaii's only commercial experience with biodiesel is production from waste cooking oil as a feedstock by Pacific Biodiesel on O`ahu and Maui. Currently, Pacific Biodiesel produces about 700,000 gallons a year.[36] Biodiesel can also be produced from animal renderings – this source should be included in any analysis of biodiesel potential. In general, animal renderings can be expected to yield nearly 60 gallons of biodiesel per ton of renderings.[37]

[36] Based in part on: Turn, Scott. Biomass and Bioenergy Resource Assessment. State of Hawaii, Hawaii Natural Energy Institute. December 2002, as well as Solid Waste Division, County of Hawaii. Study Relating to Used Cooking Oil Generation and Biodiesel Production Incentives in the County of Hawaii. December 2004, and 2002 U.S. Census Economic Census: Accommodation and Foodservices: Hawaii.

[37] "Anything into Oil", Brad Lemley, Discover Magazine, Vol. 24 No. 5. May 2003. (http://lists.envirolink.org/pipermail/ar-news/Week-of-Mon-20030804/004435.html)

4.2 Agricultural Residues and Waste Streams

Sugar cane bagasse and macadamia nut husks and shells are the two agricultural residues produced in the largest quantities in Hawai'i; however, many other residues such as pineapple wastes are prevalent on some islands. In addition to the quantity of waste available, it is important to consider density and water content (which may restrict the feasibility of transportation) and seasonality, which may restrict the ability of the conversion plant to operate on a year-round basis. Facilities designed to use seasonal biomass sources will need adequate storage space and should also be flexible enough to accommodate alternative feedstocks such as wood residues or other wastes in order to operate year-round. Some agricultural residues need to be left in the field in order to increase soil tilth and to reduce erosion. However, some residues such as bagasse can be removed after sugarcane processing without much difficulty.

4.2.1 Sugar

The sugar industry is the largest single source of agricultural biomass residues in the State of Hawai'i. These residues can be categorized into bagasse, sugarcane trash, and molasses. Bagasse is the fibrous material left after sugarcane processing. Sugarcane trash includes the leaves and stalks left in the field after the harvest. Molasses is a semi-liquid waste stream left after sugar processing. Both bagasse and molasses contain sugars that are deemed uneconomic to recover. Bagasse typically contains about 2 percent residual sugar while molasses normally contains about 50 percent sugar by mass.

Two sugar factories remain in Hawai'i: the Hawai'ian Commercial and Sugar Company (HC&S) on Maui and the Gay & Robinson Company (G&R) on Kaua`i. The bioenergy resources at the two factories are summarized in Table 4-9. In 2006, HC&S produced about 430,000 tons of bagasse at 50 percent moisture content (215,000 tons of fiber) and 60,000 tons of molasses.

Table 4-9. Potential Bioenergy Feedstocks Generated by the Hawai'i Sugar Industry in 2006.

	1000's tons			
	Bagasse*	Bagasse Fiber	Molasses	Cane Trash Fiber
Hawai'ian Commercial & Sugar Co.	430	220	60	110
Gay & Robinson	100	50	10	30

Source: USDA.

Notes:

* Bagasse at 50% moisture content

Both factories produce electricity using bagasse-fired steam boilers. HC&S also uses coal and fuel oil to firm their capacity in accordance with their power supply contract. Their power plant has three boilers with a combined capacity of about 44 MW, but normal operation only produce about 30 MW of power. G&R's power plant is rated at 4 MW, but only produces about 2 MW during normal operation. During the cane grinding season more power is normally produced than is used by the facility. This results in a net sale of electricity to the local electric cooperative. In the past, G&R sold their excess bagasse to another biomass-to-energy facility that closed in December 2002. Last year they unveiled plans for a multi-faceted "energy plantation", but have not started construction.[38]

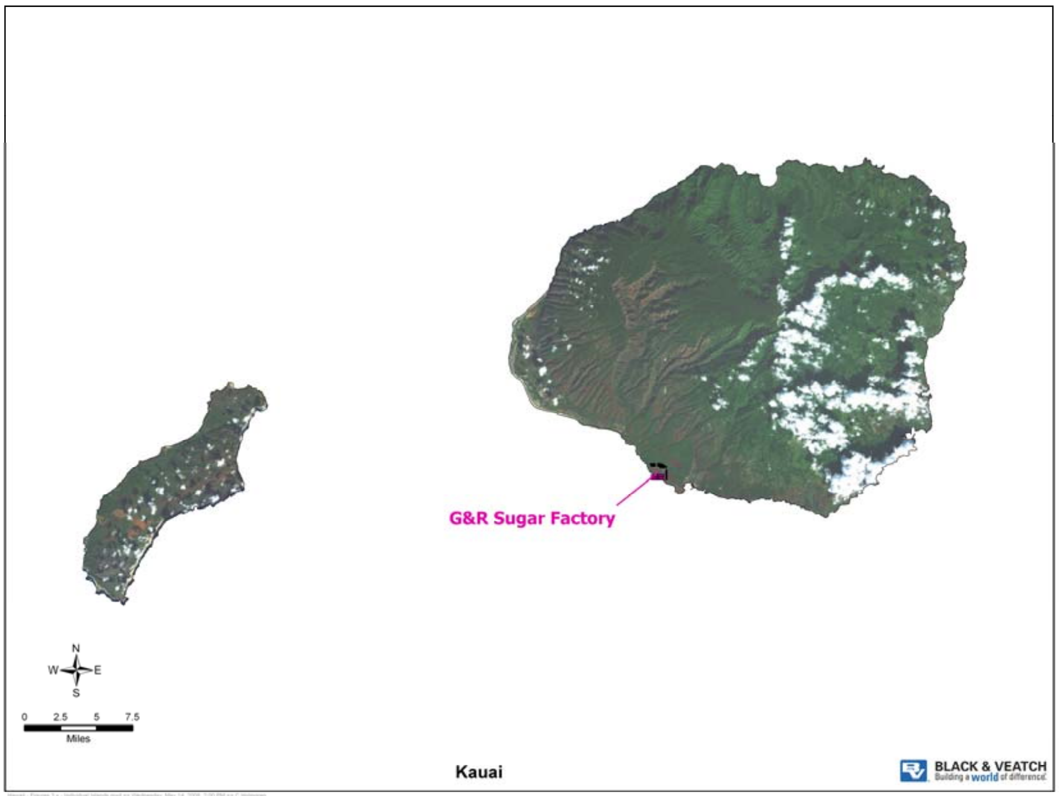

Figure 4-8. Kaua`i Sugarcane & Pineapple Waste.

As noted above, both companies produce molasses as a by-product of raw sugar manufacture. Production of ethanol via fermentation using molasses as a feedstock is a proven technology at industrial scales and a yield of approximately 72 gallons of ethanol per ton of molasses can be expected. On this basis, potential ethanol production from

[38] Eagle, Nathan. January 15, 2008. Kaua`i lawmakers set session goals. The Garden Island.

molasses for HC&S is nearly 4.3 million gallons per year. Similarly, at its current level of molasses production, G&R could expect to produce around 0.7 million gallons of ethanol per year.[39]

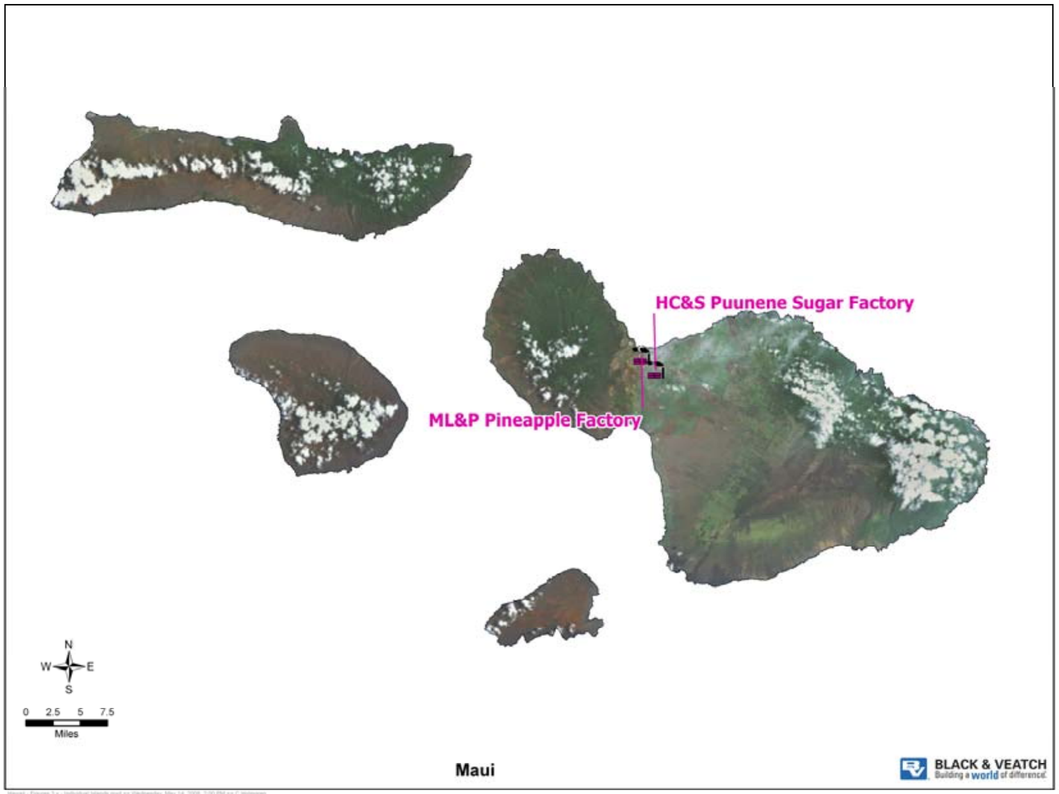

Figure 4-9. Maui Sugarcane & Pineapple Waste.

4.2.2 Pineapple

A summary of recent Hawai'i pineapple production statistics is shown in Figure 4-10. In 2005, pineapple harvested from roughly 14,000 acres in the state, totaled 212,000 tons. Of this total, half was sold as fresh fruit and the other half was processed. There are three major pineapple producers in Hawai'i. Del Monte planted their last crop in 2006 and expects to harvest the last rotation this year before giving up their lease on

[39] Turn, S; V. Keffer, and M. Staackmann. 2002. Biomass and bioenergy resource assessment, State of Hawaii. Honolulu: Hawaii Natural Energy Institute, School of Ocean and Earth Sciences and Technology, University of Hawaii.

5,100 acres. Dole announced they are considering selling some of their "non-core" land as Maui Land & Pineapple has already been doing in recent years.[40]

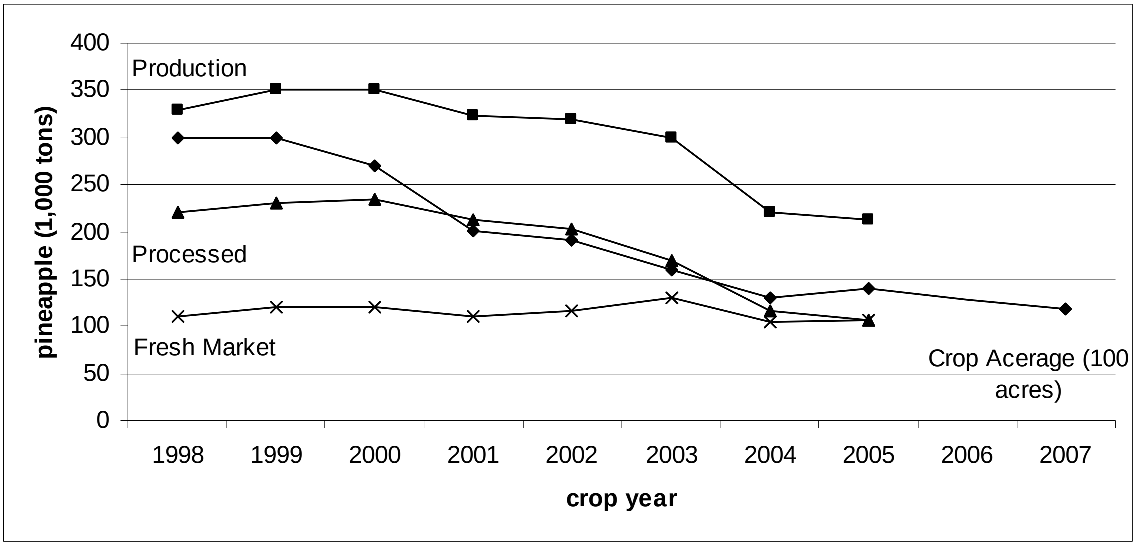

Figure 4-10. Summary of Pineapple Harvested Acreage and Production in Hawai'i for the Period 1998 to 2007.

O`ahu pineapple production is mainly sold as fresh product. Pineapples not suitable for fresh sale are canned or frozen. Some pineapple residues are produced (about 10 dry tons per acre). These are normally reincorporated back into the soil. Under circumstances that require a short turnaround time, these residues are disked, allowed to dry, and then open field burned.

Pineapple production on Maui also produces a residue in the form of dewatered skins. These are normally sold as feed to local cattle operations. This byproduct stream is estimated to be about 9,000 tons in 2007 with an estimated moisture content of 50 percent.[41] This translates to a dry matter stream of 4,500 tons on an annual basis. Field trash in handled in way that is similar to the approach used on O`ahu.

4.2.3 Macadamia Nut Shells

Macadamia nuts are de-husked and delivered nut-in-shell to the processing factories. A summary of this production from 1998 to 2006 is presented in Figure 4-11. The acreage harvested during the period declined by 4,300 acres. New macadamia nuts trees are being planted on retired sugarcane fields; however, this is not expected to be

[40] Gomes, Andrew. December 3, 2007. Dole Food Co. may sell some of its Hawaii land. The Honolulu Advertiser.

very large due to the risk of establishing new orchards. Most of the existing orchards were planted at a time when tax laws encouraged orchard establishment.

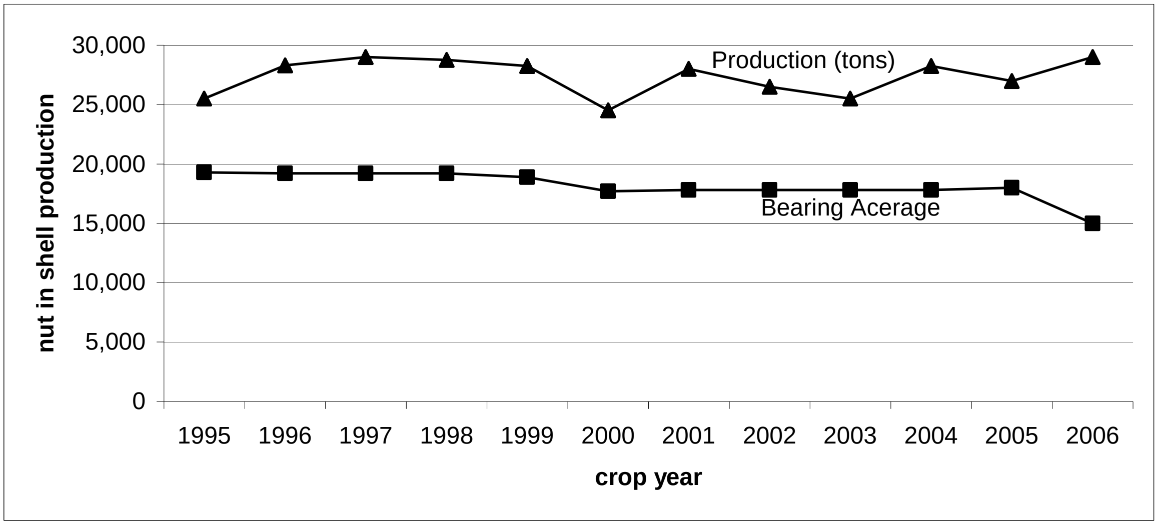

Figure 4-11. Summary of Macadamia Nut Harvest Acreages and Nut-in-Shell Production from 1998 to 2006. Crop year July 1 to June 30

Nut-in-shell production has varied from 24,500 tons to 29,000 tons with the most recent crop yield reporting 29,000 tons. Nut-in-shell normally arrives with the outer husk attached. The outer husk is removed and represents about 50 percent of the nut-in-shell mass. These husks are typically composted or used as a soil amendment. At this stage the de-husked portion of the nut contains about 20 percent moisture. These nuts are dried to about 1.5 percent moisture content before cracking. The kernel and shell have mass proportions of 25 and 75 percent, respectively. The dried shells represent about 60 percent of the moist nut-in-shell mass.[42] On this basis, an industry-wide resource of 17,000 tons per year of macadamia nut shells (at 1.5 percent moisture) is estimated.

[41] Turn, S; V. Keffer, and M. Staackmann. 2002. Biomass and bioenergy resource assessment, State of Hawaii. Honolulu: Hawaii Natural Energy Institute, School of Ocean and Earth Sciences and Technology, University of Hawaii.
[42] Turn, S; V. Keffer, and M. Staackmann. 2002. Biomass and bioenergy resource assessment, State of Hawaii. Honolulu: Hawaii Natural Energy Institute, School of Ocean and Earth Sciences and Technology, University of Hawaii.

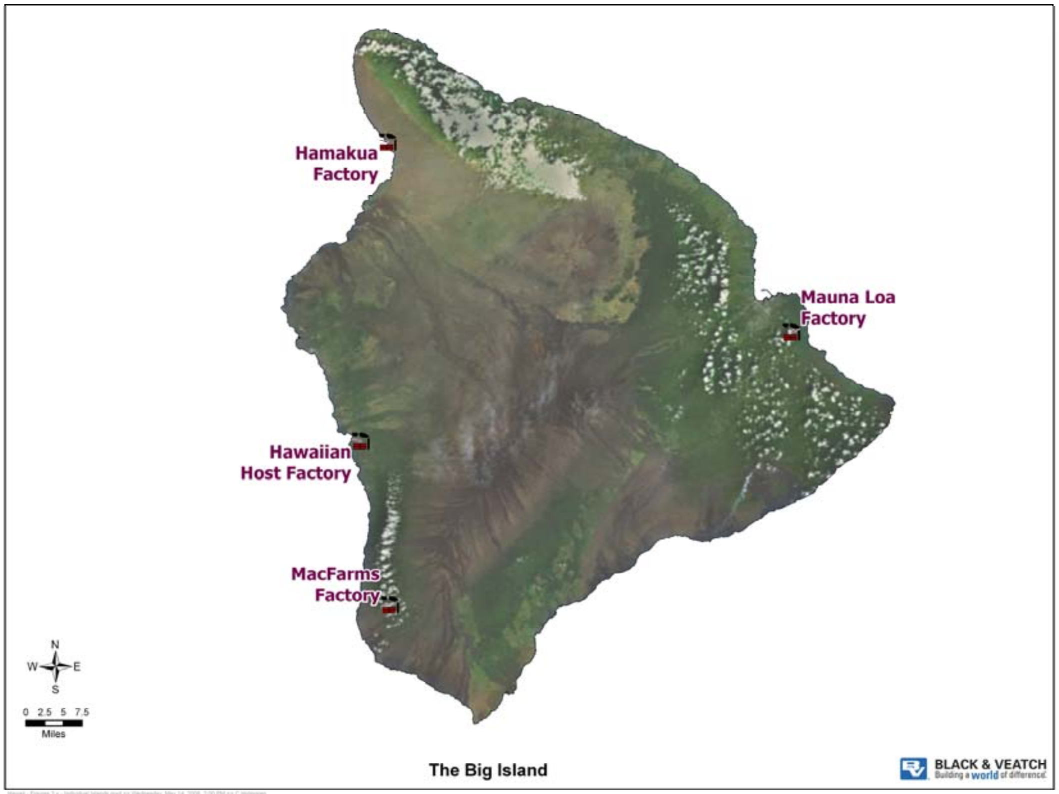

Figure 4-12. Macadamia Nut Processing Locations.

The macadamia nut shell resource is normally used as a boiler fuel to generate heat for nut-in-shell drying operations. Other uses include electricity generation, orchard road fill, and fuel in coffee drying operations in Kona. It is estimated that about ten percent of the shell residues are bought and sold amongst factories. In 2002, Turn et al. estimated this price to be $13 to $17/ton at the factory gate. Shells are normally sold by the trailer load, and the estimated weight is based on an estimated trailer volume and reasonable shell density (800 to 850 lb per cubic yard).

4.3 Animal Wastes

The main domesticated livestock populations in the state are dairy and beef cattle, hogs, and chickens. Figure 4-13 shows the population data for hogs and milk cows over the past 10 years.[43] Note that only dairy cattle numbers are shown in the figure. Although beef cattle vastly outnumber dairy cattle, their numbers do not contribute to potential manure supplies because of the dispersed character of the manure produced by

[43] Anon. November 5, 2007. Livestock and Animals. United States Department of Agriculture, National Agricultural Statistics Service.

the cattle per land area. All livestock populations in Hawai'i display a general decline for the 10-year period shown in the figure.

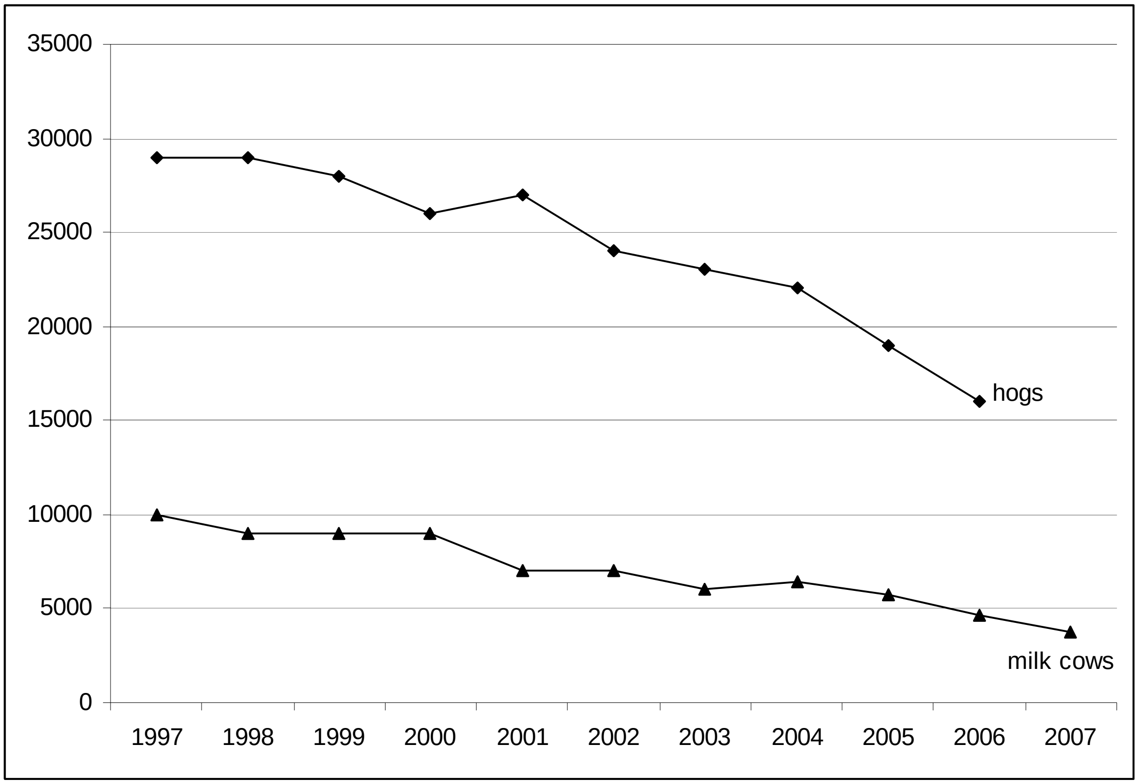

Figure 4-13. Livestock Populations in Hawai'i for the Period from 1997 to 2007.

4.3.1 Swine Manure

Hawaii's total hog population is about 15,000 animals, with about 3,500 used as breeding stock and the remainder sold to market. Geographic data on hog populations for 2006 are shown in Table 4-10 (data for 2007 was not yet available). Hog farms in Honolulu County are small and average only three acres in size.[44]

[44] Zalefki, H. Personal communication between Halina Zalefki (University of Hawaii Swine Extension specialist) and Bret Harper.

Table 4-10. Summary of Swine Populations and Hog Farms Sizes in Hawai'i, 2006 Data.		
County	**All Hogs**	**Change from 1997**
Hawai'i	900	- 1,300
Kauai	2,000	- 1,500
Maui	3,500	- 1,400
Honolulu	9,600	- 8,800
State Total	**16,000**	**- 13,000**
Source: Hawai'i County Data – Livestock. USDA National Agricultural Statistics Service – Quick Stats. (http://www.nass.usda.gov/QuickStats/indexbysubject.jsp?Text1=&site=NASS_MAIN&select=Select+a+State&Pass_name=&Pass_group=Livestock+%26+Animals&Pass_subgroup=Livestock)		

Total manure production was based on hog weight as shown in the figure below. In order to produce the current information on hog populations, the total number of hogs in 2007 (15,000 head) were assumed to be dispersed in the same proportions as in 2006. Based on these populations, manure production was calculated using the same method as the Turn et al. (2002) report. This hog manure information is presented in Table 4-11.

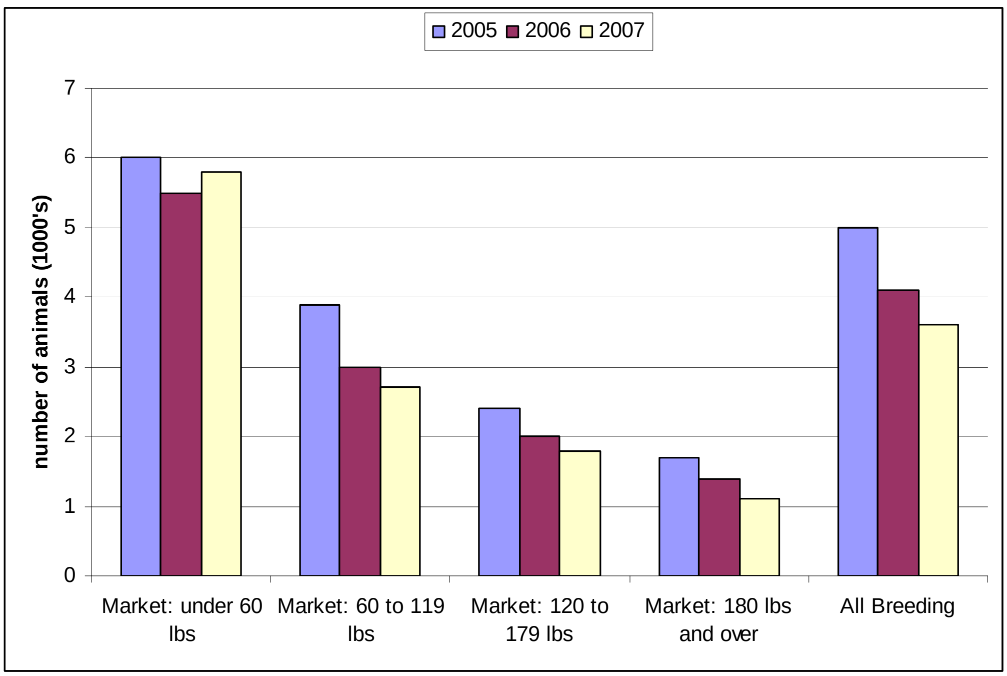

Figure 4-14. Distribution of Hog Sizes in the 2008 Swine Industry.[45]

[45] Anon. 2008. Hawaii County Data – Livestock. USDA National Agricultural Statistics Service – Quick Stats. (http://www.nass.usda.gov/QuickStats/Create_County_Indv.jsp)

Table 4-11. Summary of Hog Populations and Manure Production by County.

	1,000's			
	No. of Hogs [a], Y2006	Estimated No. of Hogs [b], Y2007	Estimated Annual Production Y2007 [c], (wet tons / year)	Estimated Annual Production, Y2007 [d], (dry tons / year)
Hawai'i County	0.9	0.8	1,000	90
Maui County	3.5	3.3	4,000	370
Honolulu County	9.6	9.0	11,100	1,020
Kaua`i county	2.0	1.9	2,200	200
Total	16	15	18,400	1,690

Source: Hawai'i County Data – Livestock. USDA National Agricultural Statistics Service – Quick Stats. (http://www.nass.usda.gov/QuickStats/Create_County_Indv.jsp).

Notes:

[a] Data from USDA Statistics Service, 2008.
[b] Based on county distribution from Y2006 and state total for Y2007.
[c] Based on hog sizes shown in Figure 3-4, and manure estimates from Turn et al. (2002).
[d] Based on moisture content of 90.8%.

4.3.2 Cattle Manure

As shown in Table 4-12, there were about 3,800 milk cows in Hawai'i in 2007. The number of total cattle during the same period was about 158,000. When considering options to collect biomass residues, only animals raised at high density present an opportunity for manure collection at a reasonable cost. Beef cattle are typically raised on pasture at low density, so dairy cows are the main source of cattle manure. As recently as 1980, Hawai'i had about two dozen dairies and was totally self-sufficient in milk. Since 1999, however, four dairies on O`ahu and three on the Big Island have closed. Pacific Dairy, the last dairy on O`ahu shut down in early 2008, leaving the island's 910,000 residents dependent on imported milk. The closing of Pacific Dairy in Waianae Valley will leave Hawai'i with just two dairies, both on the Big Island, which produce milk almost exclusively for that island[46] and are also pasture based. This leaves no cattle being raised at high density and therefore no biomass residues available from cattle.

[46] Hao, Sean and Dan Nakaso. January 30, 2008. Last dairy closing in Oahu; milk a concern. USA Today.

Table 4-12. Cattle and Calves: January 1 Inventory by Sex Classes and Weight, State of Hawai'i, 2003-2007.

Year	All cattle and calves	All cows and heifers that have calved			Heifers 500 pounds and over				Steers 500 lbs. and over	Bulls 500 lbs. and over	Steers, heifers, and bulls under 500 lbs.
		Total	Beef cows	Milk cows	Total	Beef cow replace-ments	Milk cow replace-ments	Other			
						1,000 head					
2003	151	86	79	7	21	12	3	6	7	5	32
2004	156	88	82	6	20	12	2	6	7	5	36
2005	155	87	81.3	5.7	22	15	2	5	7	5	34
2006	161	92	87.4	4.6	22	15	2	5	7	5	35
2007	**158**	**89**	**85.2**	**3.8**	**21**	**15**	**1**	**5**	**8**	**5**	**35**

Source: Anon. February 22, 2007. Hawai'i Cattle January 1. National Agricultural Statistics Service, United State Department of Agriculture in cooperation with the Hawai'i Department of Agriculture.

4.3.3 Poultry Manure

Published information on the number and size of chicken operations in Hawai'i is limited because of the need to avoid disclosing information about individual farms. Data on laying birds is available from United States Department of Agriculture (USDA).

Daily manure production values are based on the methods used by Turn's 2002 *Biomass and Bioenergy Resource Assessment*, assuming no broiler chickens since the closure of Pacific Poultry's slaughter side of operations in late 2004. Using an estimate of 550,000 chickens in the state, down from 883,000 in 2001, these chickens produce an estimated 4,000 dry tons of manure per year.

Table 4-13. Estimates of Chicken Inventories and Manure Resources in Hawai'i.

	Total
Animal Inventory* (thousands)	550
Manure Production Rate (lb/animal/day)	0.16
Annual Manure Production (wet tons/year)	16,000
Annual Manure Production**(dry tons/year)	4,000

Notes:
* 2006 inventory data from USDA
** Assumes moisture content of 75%

Poultry manure is high in nitrogen and is used directly as a soil amendment. It is also being mixed with mulch and composted, then sold wholesale in bulk or retail bags. Poultry manure also has potential for use as a feedstock in thermochemical and anaerobic digestion processes.

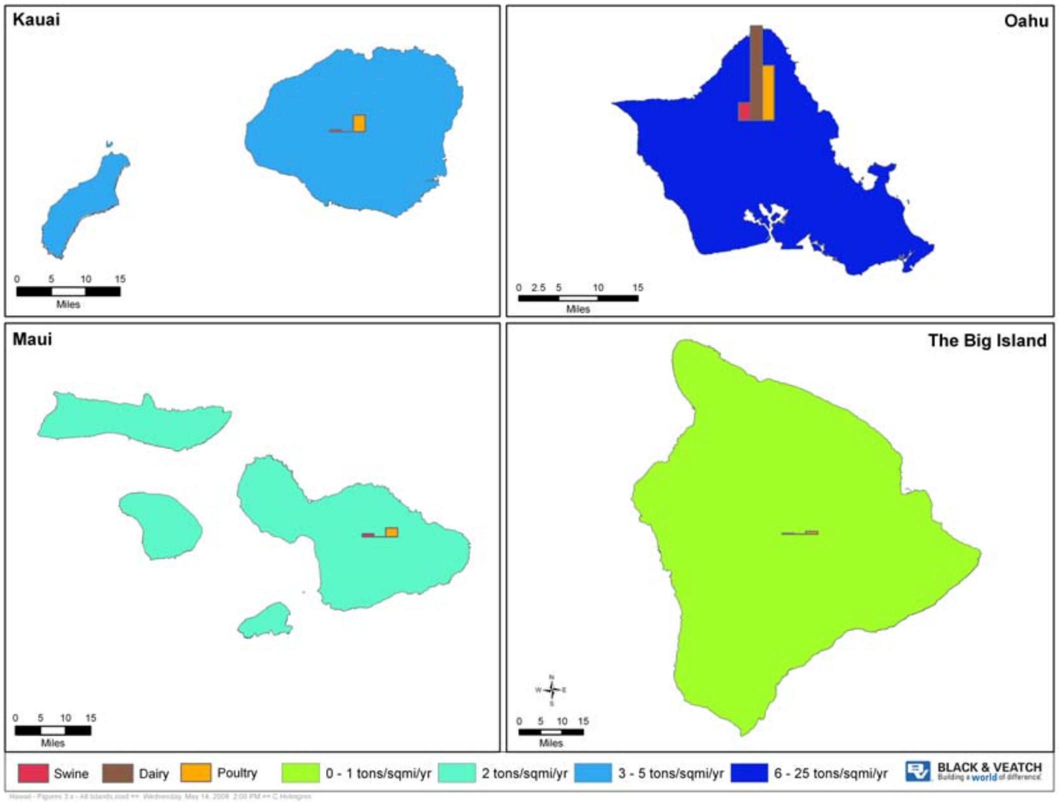

Figure 4-15. Animal Wastes.

4.4 Wood Resources

The Hawai'ian Islands support a wide variety of forest types, ranging from low elevation tropical rain forests to arid scrub forests to temperate sub-alpine woodlands to cloud forests. These forests still cover roughly 1.7 of Hawaii's 4.1 million acres, or about 41 percent of the state's total land area. Approximately 60 percent of this area is considered to be productive, healthy forest, covered primarily by ohia (*Metrosideros polymorpha)*, ohia-koa mix, and relatively pure koa (*Acacia koa*).[47]

[47] Anon. 2001. Hawaii's 5-Year Forest Stewardship Plan. State of Hawai`i, Department of Land and Natural Resources, Division of Forestry and Wildlife.

Table 4-14. State Forest Reserves.

Location	Forest Reserves	Approximate Acres
Kaua`i	8	76,000
O`ahu	14	31,000
Maui & Moloka`i*	9	83,000
Big Island	22	448,000
Total	**53**	**637,000**

Source: Hawai'i Forest Reserve System. State of Hawai`i, Department of Land and Natural Resources, Division of Forestry and Wildlife.

Notes:

* There are no state forest reserves on Kaho`olawe or Lana`i

About 700,000 acres, or roughly 50 percent of Hawaii's relatively productive forest land are considered to be timberland, capable of producing timber and wood products on a sustainable basis. Only about 60,000 of these acres are currently being used for plantation forestry.[48]

[48] Anon. 2001. Hawaii's 5-Year Forest Stewardship Plan. State of Hawai`i, Department of Land and Natural Resources, Division of Forestry and Wildlife.

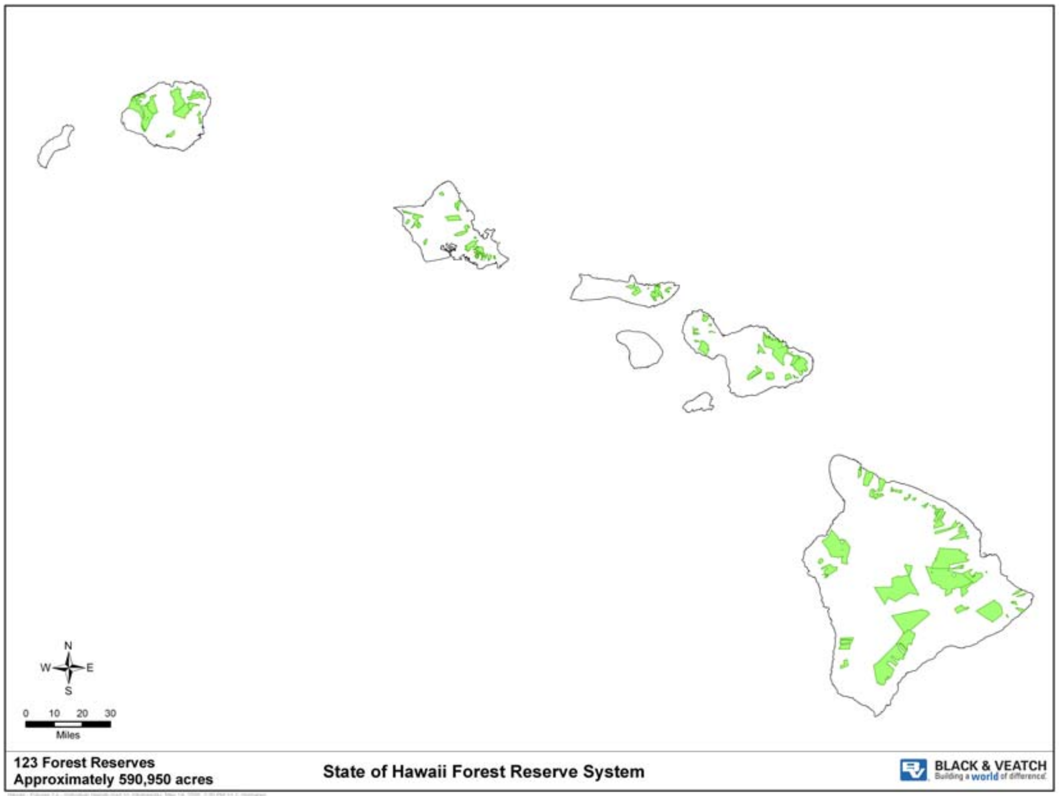

Figure 4-16. State of Hawai'i Forest Reserve System.

4.4.1 Forest Products

A 1994 report[49] estimated the required forest area and annual timber volume necessary for various forest industry products. These are shown in Table 4-15. This report assumed a ramp-up of the industry over 15 years. It also assumes that wood-waste from lumber production would be integrated into the wood chip and fiberboard production. If these industries were not integrated, more wood waste would be available for biofuel production.

[49] Anon. 1994. Hawaii Forestry Investment Memorandum. Prepared for the State of Hawaii Department of Business, Economic Development & Tourism by Groome Poyry Limited, Auckland, New Zealand.

Table 4-15. Summary of Product Options and Associated Forest Area and Timber Requirements for Hawai'i Processing Facilities.

Product	Required Forest Area (acre)	Required Annual Timber Volume* (million cubic feet)
Wood chips for export	30,000	17.7
Medium density fiberboard	10,000	6.4
Dimensional lumber	4,000	4.2
Veneer	15,000	1.1

Source: Hawai'i Forestry Investment Memorandum. Prepared for the State of Hawai'i Department of Business, Economic Development & Tourism by Groome Poyry Limited, Auckland, New Zealand.

Notes:

* Volume requirement assumed integration of facilities.

4.4.2 Forest Resources

A second study[50] completed in 2000, inventoried the timber available on State Lands. Some of the details of this study are given in Table 4-16. The island of Hawai'i has the greatest potential for commercial timber operations. About 12,000 acres of timber exist on the Waiakea Timber Management Area. This area was originally planted in the mid-1960 and some tracts have been harvested and replanted. Most of the species found in the WTMA are non-native with the exception of about 500 acres of ohia and koa. The *Eucalyptus saligna* and *E. grandis* species are most abundant. The WTMA is not a contiguous parcel, but a collection of timber stands contained in a rectangle about 5 miles wide and 12 miles long boarding Highway 19 leaving Hilo.

[50] Anon. 2000. *Market Research on Commodity Wood Products from 8 Non-Native, Hawaiian Grown Timber Species*. Prepared by Jaakko Poyry Consulting (Asia-Pacific) Pty. Ltd. The Jaakko Poyry report was prepared for the Hawaii Forest Industry Association with funding from the Hawai`i Forestry & Communities Initiative.

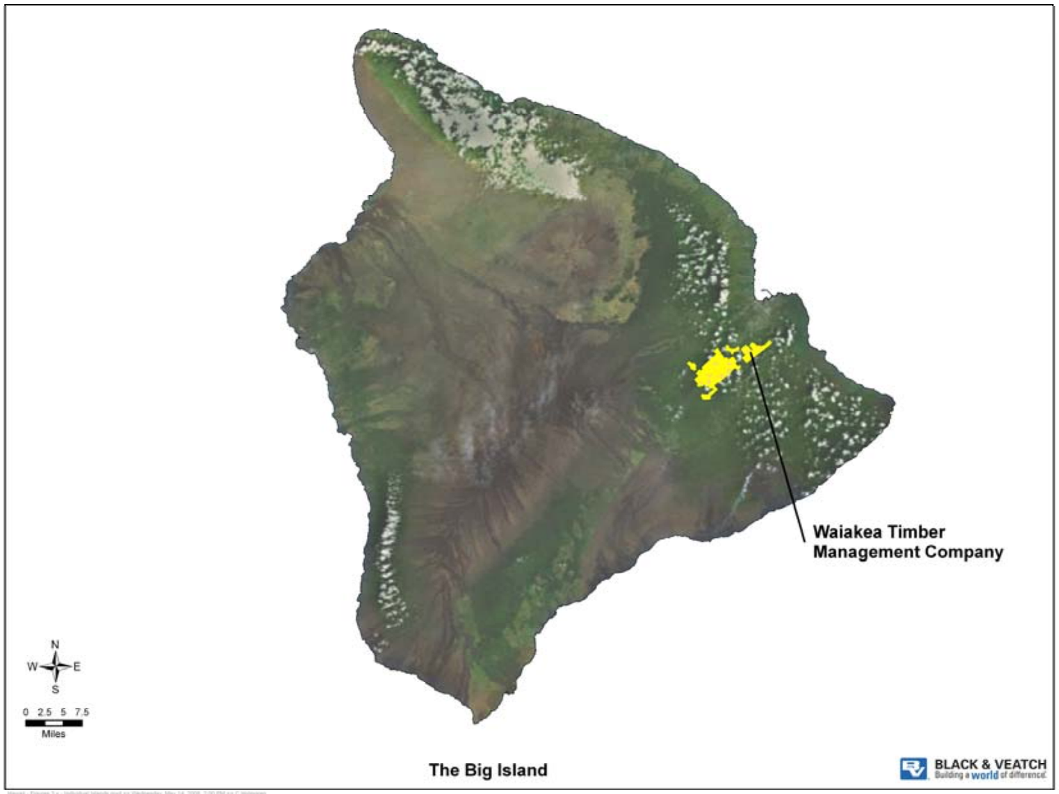

Figure 4-17. Waiakea Timber Management Area.

Since early this decade, Tradewinds Forest Products LLC (Tradewinds) has had a license to log non-native timber on the 12,000 acre Waiakea Timber management area just south of Hilo, but more timber had been needed to operate a proposed veneer mill on a continuing, sustainable basis. Recently Tradewinds announced that it had acquired lease rights to 6,100 additional acres near Pahala in the Kau District, about 50 miles south of Hilo. The acreage is comprised of two parts: 3,700 acres for timber, and 2,400 acres of native forest that will remain in conservation.[51] With suitable timber acreage now secured, Tradewinds is planning to open a veneer mill that is expected to produce 84 million square feet of veneer and 2 to 3.6 MW of biomass energy utilizing mill residues.

[51] Thompson, Rod. August 8, 2007. New mill secures sufficient source of wood. Honolulu Star Bulletin, Vol. 12, Issue 220

Table 4-16. Summary of Timber and Bioenergy Resource Estimates Based on a 15 Year Harvest Schedule.

	Harvestable Area (acres)	Annual Volume (10^3 ft^3)	Annual Sawmill Residues (tons)	Annual Pulpwood (tons)	Annual Sawdust & Bark (tons)	Annual Biomass Resource Estimate (tons)
Tradewinds	7,800	2,600	30,000	40,000	9,000	79,000
Hawai'i Island Hardwoods*	2,000	420	5,000	6,000	1,000	12,000
Other (Big Island)**	1,500	310	4,000	5,000	1,000	10,000
Other (Kaua`i)**	1,600	340	4,000	5,000	1,000	10,000
Total	12,900	3,670	43,000	56,000	12,000	111,000

Notes:

* Based on Y2010 expectations, given similar acreage requirements and residue production as the Tradewinds operation.

** Based on Hawai'i Forest Stewardship Program participation. These figures include acreage under active management for the forest industry. As many as 40,000 additional acres may be available from private commercial forests and the Hamakua coast timber area on the Big Island.

Hawai'i Island Hardwoods LLC is also planning a new mill on the Big Island that is being planned for a capacity of 2 million board feet of lumber per year in year one and it is anticipated that production will increase to over 5 million board feet by year three.[52]

On Kaua`i, Green Energy Hawai'i has partnered with Hawai'ian Mahogany to provide woodchips and other biomass for a planned 7.1 megawatt wood gasification power plant. Hawai'ian Mahogany presently leases approximately 3,600 acres and has planted more than one million trees. They also plan to grow trees on about 1,000 acres of state land in Kaua`i. The bulk of their plantings use two particular species of Eucalyptus, which provide high-grade quality, cabinet grade wood. The Eucalyptus is inter-mixed with another tree, Albizia, which provides nitrogen and other nutrients. The Albizia trees will be harvested as a woody energy crop to provide fuel for the Green Energy Hawai'i gasifier. By using Albizia, Hawai'ian Mahogany has dramatically cut the need for commercial fertilizers by 95 percent, which is both economically and environmentally advantageous. However there have been some emerging concerns expressed that Albizia is a non-native/invasive species. The Division of Forestry and Wildlife, in the Hawai'i Department of Land and Natural Resources, has asked Green Energy Hawai'i to provide a 10-year plan showing a phasing from Albizia to a less invasive species on state lands.

[52] Lucas, Carolyn. January 16, 2008. Wood You Believe? West Hawaii Today.

Green Energy Hawai'i is developing plans to grow a non-invasive species as a replacement for Albizia for the tree plantations gown on state lands.[53] Green Energy Hawai'i is working to finalize permits for its biomass-to-energy plant.[54]

4.5 Biomass Residue Resource Summary and Conclusions

An assessment of the biofuel feedstock from residual sources was performed. Urban, agricultural, livestock, and forest industry waste was considered. The urban waste was divided by county. Agricultural waste included residues from the sugar, pineapple and macadamia nut industries. Only domesticated livestock manure housed in relatively high density was included in the livestock waste estimates.

Table 4-17 summarizes the biomass residues available in Hawai'i, along with an estimation of the current utilization. Unutilized residues could be used for biofuel production. Currently utilized residues could be diverted to higher value products, which might include liquid biofuels production. The future availability of these resources will depend on local, national, and international markets, policy, and regulations.

[53] Paik, Shelly. April 4, 2006. Green Energy Hawaii Selected for Biomass-To-Energy Facility Project. Kaua`i Island Utility Cooperative.
[54] Eagle, Nathan. January 15, 2008. Kaua`i lawmakers set session goals. The Garden Island.

Table 4-17. Summary of Biomass Residues and Biomass Residue Utilization in the State of Hawai'i Broken Down by County.

	Tons/yr	Hawai'i	Maui	Kaua`i	Honolulu
Solid Waste	As-received	300,000 (80,000)[a]	350,000 (80,000)[a]	120,000 (30,000)[a]	1,600,000 (500,000)[a]
Sewage Sludge	Dry	200	3,400 (3,400)[a]	200	16,600 (900)[a]
Fat, Oil, Grease	Dry	1,900	1,900 (1,900)[a]	1,000	10,000 (1,900)[a]
Bagasse Fiber	Dry		220,000 (220,000)[a]	50,000 (50,000)[a]	
Cane Trash	Dry		110,000	30,000	
Molasses	As-received		60,000	10,000	
Pineapple Processing Waste	Dry		4,500 (4,500)[a]		0
Macadamia Nut Shells	Dry	17,000 (17,000)[a]			
Dairy Manure	Dry	0			0
Poultry	Dry				5,000
Swine Manure	Dry	90	370	200	1,020
Forest Industry	Dry	101,000		10,000	
Gross Total		**420,190**	**750,170**	**221,400**	**1,632,620**
Landfill Gas	Ft^3/day	300,000		700,000	576,000

Notes:
[a] Amount currently used.

4.6 Biofuel Production Potential

Biofuel production potential can be evaluated based on the identified biomass resources. The following sections look at potential for ethanol, biodiesel and hydrogen derived from biomass.

4.6.1 Ethanol

Table 4-21 shows the amount of ethanol that can be produced in Hawai'i using the biomass residue resource estimates presented in above. The ethanol potentials expressed for enzymatic hydrolysis and thermochemical processes are mutually exclusive, as both are derived from the same total statewide available feedstock.

Note that total gasoline consumption in Hawai'i was about 475 million gallons per year (MGY) in 2007. If ethanol is used as a 10 percent blend in all gasoline sold in the state, the total demand for ethanol in Hawai'i would be about 72 MGY (adjusting for equivalent gallons of gasoline). Replacing 15 percent of the State's gasoline demand (the State's goal for 2015) corresponds to 107 MGY of ethanol (with the simplifying assumption that demand stays the same as current levels with advances in vehicle fuel efficiencies). Replacing 20 percent of the State's gasoline consumption would require 143 MGY of ethanol (corresponding to the State's renewable fuel goal for the year 2020). Achieving the replacement of 15 to 20 percent of gasoline consumption in Hawaii with ethanol would be facilitated if a portion of the vehicle fleet includes flexible fuel vehicles that can use gasoline/ethanol blends with up to 85 percent ethanol (D85).

Table 4-18. Total Hawai'i Ethanol Potential from Available Residues.

Ethanol Type	Feedstock	Total Hawai'i Potential (million gal/yr)
Conventional Ethanol	Molasses	4.8 – 5.0
Enzymatic Hydrolysis	Cellulosic wastes*	66 – 99*
Thermochemical (self-sufficient)	Cellulosic wastes*	88 – 100*
Thermochemical (maximum alcohol)	Cellulosic wastes*	120 – 140*

Notes:
* Resources include bagasse, sugar cane trash, macadamia nut shells, pineapple waste, and urban cellulosic waste. These numbers include resources that would be diverted from the H-POWER generation facility.

4.6.2 Biodiesel

Table 4-19 shows the amount of biodiesel that can be produced in Hawai'i. For Fischer-Tropsch diesel, the potential feedstock is the same as that for cellulosic ethanol. As such, the potential listed for Fischer-Tropsch diesel is not additive with the potentials listed in Table 4-18 for cellulosic ethanol.

Table 4-19. Total Hawai'i Biodiesel Potential.

Conversion Pathway	Feedstock	Total Hawai'i Potential (million gallons per year)
Transesterification	Waste oil	2.0 – 2.5 *
Fischer-Tropsch Diesel	Cellulosic wastes**	83.0 – 98.0 **

Notes:

* From Hawai'i Biofuels Summit Briefing Book. Based in part on: Turn, Scott. Biomass and Bioenergy Resource Assessment. State of Hawai\`i, Hawai'i Natural Energy Institute. December 2002, as well as Solid Waste Division, County of Hawai\`i. Study Relating to Used Cooking Oil Generation and Biodiesel Production Incentives in the County of Hawai\`i. December 2004, and 2002 U.S. Census Economic Census: Accommodation and Foodservices: Hawai\`i.

** Resources include bagasse, sugar cane trash, macadamia nut shells, pineapple waste, and urban cellulosic waste. These numbers include resources that would be diverted from the H-POWER generation facility.

4.6.3 Biomass Derived Hydrogen

Table 4-20 shows the amount of hydrogen that can be produced in Hawai'i using the identified residue resources. Both landfill gas and anaerobic digestion gas feedstocks are limited in Hawai'i.

Table 4-20. Total Hawai'i Hydrogen Potential.

Residue Resource	Feedstock	Total Hawai'i Potential
Methane Reformation	Landfill Gas	950 million scf/yr
Biomass Gasification	Cellulosic wastes	15 billion scf/yr*
Microorganisms	Cellulosic wastes	Unknown

Notes:

* Assumes an average feedstock moisture content of 50%.

4.7 Potential Future Markets for Biomass Residues

Of all forms of biofuel feedstocks, biomass residues offer the best immediate opportunity for local feedstock supply, in addition to the social benefits such as waste reduction (which is a major challenge on every island in the state). Biomass residues are especially competitive when costs of production are partially defrayed due to production activities associated with the processing of another product, e.g. sugar or macadamia nuts. The potential future markets for each category of biomass residues are addressed below.

Urban green waste flows have drastically grown amongst composting operations throughout the state; however, these are likely to be leveling off. Both Honolulu and Kaua\`i already have laws prohibiting green waste at their landfill and waste-to-energy facilities. Even if the counties are successful in diverting more green waste from landfill disposal, the waste composition studies show that the current landfill streams generally contain less than 10 percent green waste. Urban waste is expected to grow proportionally with Hawai'i de facto population at a rate of about 1.0 percent per year.

The cane sugar production for Hawai'i is up slightly at 1.78 million tons, which is 6 percent increase from the 1.68 million tons in 2006.[55] A decade ago, Hawai'i was regularly producing only 300,000 tons per year.[56] Increased mechanization, increased demand for sugar sales to the US mainland and renewable portfolio standard compliance are some of the leading causes for expansion of the industry. Since 1992, ten out of 12 mills have closed with the most recent closing in 2000.[57] Some of the currently operating mills also have been losing money in recent years, but with demand for local ethanol production on the rise, growth of the industry is expected in coming years. Production in calendar year 2008 is forecast to increase modestly, ending a decade of rapid contraction of the industry. Gay & Robinson last year unveiled a multi-faceted: "energy plantation" and Green Energy Hawai'i is working to secure permits for its proposed biomass-to-energy plant. Neither company has started construction.[58] At the same time, however, the pineapple industry is slumping as pineapples are being grown and shipped cheaply to the United States from Thailand, the Philippines, Brazil, China, India, and Costa Rica. Del Monte Fresh Produce has announced that in 2008, it will cease its pineapple production in Hawai'i leaving only Maui Land and Pineapple and Dole to the industry. Macadamia nut production has increased in recent years as more pineapple fields become available.[59]

The Hawai'i livestock and poultry industries, which include primarily small to medium size business enterprises, are also declining. For many cattle producers, the main source of income from cow-calf operations and the sale of weaned calves, grass finished steers and heifers, and spent cows and bulls.[60] During 2007, the total Hawai'i inventory of cattle and calves declined by 2 percent from 2006 levels. The development and increasing market demand for premium priced, locally grown, finished and branded "organic" and "natural" beef on the Big Island has kept the total cattle marketing for 2006 at 61,000 head, up 13 percent from 2005 and the highest total in six years. The dairy industry, however, totaled 3,800 head on January 1, 2007, a 17 percent or 800-head

[55] Anon. December 5, 2007. Isle sugar cane production growing. Business Briefs, The Honolulu Advertiser.
[56] Anon. 1997. The North American Sugar Market: Recent Trends and Prospects Beyond 2000. Proceedings of the Fiji/FAO 1997 Asia Pacific Conference.
[57] Ruel, Tim. September 15, 2000. Amfac to quit farming on Kauai. Honolulu Star Bulletin.
[58] Eagle, Nathan. January 15, 2008. Kaua`i lawmakers set session goals. The Garden Island.
[59] Niesse, Mark. April 24, 2006. New crop flourishing in place of pineapple. Honolulu Star Bulletin, Vol. 11, Issue 114.
[60] Anon. October 10, 2001. Five-Year Plan. Hawai`i State Department of Agriculture, Animal Industry Division, Livestock Disease Control & Veterinary Laboratory Branch.

decrease from a year earlier. At the end of 2006, Hawai'i had five commercial dairies,[61] but by early 2008 this number had dwindled down to two. The decline in Hawaii's dairy sector is the result of rising feed, shipping and land costs, environmental regulations, and stagnant sales.[62]

During 2007, the hog inventory also declined by 15,000 head (-6 percent) from 2006. The inventory of hogs has been declining for several years and is down 35 percent from 2003[63].

Hawai'i egg producers are in direct competition with US mainland producers for Hawai'i markets. Egg production presents challenges anywhere, but Hawai'i companies face added obstacles such as rising fuel prices, further boosting shipping costs of feed and equipment. Higher costs for land, water, electricity, and labor have left only six commercial egg producers statewide (four on O`ahu, one on the Big Island, and a smaller operation on Maui). Medeiros farm on Kaua`i is the only farm in the state selling "broilers," all of which are consumed on Kaua`i. Pacific Poultry shut down the slaughter side of operations late in 2004, so there no longer is a broiler chicken industry on O`ahu.[64]

Forestry in Hawai'i is primarily about protecting the island watersheds, providing habitat for rare and endangered species, and providing recreation for local people and visitors. A small but important local forest industry is based on the harvest of native woods such as koa and ohi`a, traditional Hawai'ian woods such as kamani and milo, and exotic woods such as Eucalyptus and mango. These locally harvested timbers are currently made into high-quality bowls, furniture, picture frames, and flooring. Small forestry operations (<100 acres) that specialize in Hawai'ian hardwoods have been encouraged by the State for many years with the hope of demonstrating Hawaii's viability to the larger lumber and veneer industry. With the expected opening of two new medium sized saw mills on the Big Island, 2008 looks like a promising year for further forest industry development.

[61] Anon. February 22, 2007. Hawai`i Cattle January 1. National Agricultural Statistics Service, United State Department of Agriculture in cooperation with the Hawai`i Department of Agriculture.
[62] Hao, Sean and Dan Nakaso. January 30, 2008. Last dairy closing in O`ahu; milk a concern. USA Today.
[63] Anon. January 31, 2008. Hog inventory falls again, to 15,000. Business Briefs, Honolulu Advertiser.
[64] Watanabe, June. December 4, 2005. Pork and poultry fall to isle market reality. Star Bulletin, Vol. 10, Issue 338.

Table 4-21. Summary of Biomass Residue Future Market Supply.

	Future residue supply
Urban Waste	Up
Agricultural Residue	Up
Livestock Manure	Down
Forest Industry Residue	Up

Sustained high world oil prices and the passage of the EPACT 2005 have encouraged the collection and use of low-density residues from the urban, agricultural, livestock, and forest industries; however, both the continued growth of the biofuels industry and the long-term market potential for biofuels depends on larger quantities of biomass feedstocks being produced. For each of the major biofuels (sugar-based ethanol, cellulosic ethanol, and biodiesel) resolution of technical, economic, and regulatory issues remain critical to further development of biofuels feedstocks in Hawai'i.

4.8 Conclusion

There are significant opportunities for increased biofuel production from wastes in Hawai'i. Table 4-22 shows the potential for ethanol, biodiesel, and hydrogen production using Hawai'ian waste resources.

Table 4-22. Total Hawai'i Biofuel Potential from Waste.

Fuel	Feedstock	Total Hawai'i Potential
Ethanol	Cellulosic wastes	90 million gallons/yr*
Ethanol	Molasses	5 million gallons/yr
Biodiesel	Waste oil	2.0 – 2.5 million gallons/yr
Hydrogen	Landfill gas	950 million scf/yr

Notes:
* Represents a middle number common to both thermochemical and biochemical potentials.

5.0 Energy Crop Potential

The objective of this section is to estimate the feedstock production potential for energy crops grown agricultural land in Hawai'i. Two different classes of land are examined. First production potential from rainfed non-prime agricultural land is investigated. Second production potential on irrigated prime land is explored. The section has the following topics are addressed in this section:

- Crop Land in Hawai'i—A description of the soils and climate in Hawai'i and criteria for selecting potential biofuel crop land.
- Estimating Crop Yield—The use of analogous environments to estimate yield of the candidate crops on the selected lands.
- Production of Biofuel Crops—Production of feedstock and a comparison of fuel production and fuel consumption in Hawai'i.
- Recommendations—Recommendations to increase production of fiber and oil feedstock.

5.1 Crop Land in Hawai'i

The Natural Resource Conservation Service (NRCS) has classified all soils in Hawai'i and is an essential source of information for crop production (SCS, 1972; SCS, 1973). In its classification scheme, the NRCS uses factors such as soil temperature, soil moisture, rockiness, land forms, and slope of the land to distinguish one type of soil from another. The NRCS classifications have been used in this analysis.

There are four classes of soil temperature found in the tropics. The term isofrigid describes soil that has a mean annual temperature of less than 46° F measured at 20 inch depth. Isomesic means soil that has an average temperature between 46° F and 59° F. Isothermic refers to soil with an average temperature between 59° F and 72° F. Isohyperthermic describes soil that has an average temperature greater than 72° F. From this point forward, the terms isomesic, isothermic, and isohyperthermic will be replaced with cold, cool, and warm, respectively. Isofrigid soils are inappropriate for energy crop use and are excluded from this analysis.

Soil moisture descriptions are based on the number of months that it can supply water to plants. The supply of water is dependent on the amount of rain and the ability of the soil to store water. The term aridic is applied to soils that can supply plant water needs for less than half a year. Ustic describes soils that supply water to plants for 6 to 9 months of the year. Soils that supply water to plants for more than 9 months are called udic. When soils have more water than can be evaporated or are saturated, they are called perudic and aquic, respectively. The terms aridic, ustic, udic, perudic, and aquic will be replaced with the common words dry, moist, wet, very wet, and saturated in this analysis.

Certain soil types were excluded from this analysis because of their inappropriateness for growing crops. Areas that have excessive stones, shallow soil, and/or rock outcrops are poor for crop production. Slope of the land is an important factor for tractor operation and runoff. Most crop lands have slopes less than 20 percent while pasture has less than 35 percent slope.

In summary, the non-irrigated land in Hawai'i considered for biofuel production is based on the following criteria:

- Land is zoned for agriculture.
- Land is not designated as prime or unique within the land zoned agriculture.
- Rough broken, very stony, and rocky lands are excluded.
- Lava land is excluded.
- Land slope is less than 20 percent.

Based on these characteristics, approximately 814,501 acres of total land is suitable for biofuel crop production on the islands of Hawai'i, Maui, Molokai, Kauai, Oahu, and Lanai.

Maps that show the distribution of these potential biofuel crop lands were prepared from spatial data obtained from the Hawai'i Statewide Geographic Information System (GIS) Program (Office of Planning, 2008). The maps were characterized to show the soil temperature and moisture classes for each island (Figures 5-2 through 5-13). In general, low lying lands are classified as warm and the class changes to cool and cold when moving upslope. Soil moisture is higher along the windward (northeast) side of the islands and drier on the leeward (southwest) side. Exceptions to this pattern are caused by pockets of sandy soil that appear as drier soil in the middle of wet areas, or poorly drained soil, which appears as pockets of wet in dry areas.

Most of the land is classified as moist or wet and is capable of supporting plant growth, about 683,000 acres. These moist and wet lands run across temperature classes that range from warm to cold. The Big Island of Hawai'i has 653,000 acres of the potential biofuel crop land, 80 percent of the total available. Maui has the next largest portion with 90,000 acres, or 11 percent. The remaining 9 percent is distributed among Molokai, Kauai, Oahu, and Lanai. A summary breakdown by land type and island can be seen in Figure 5-1.

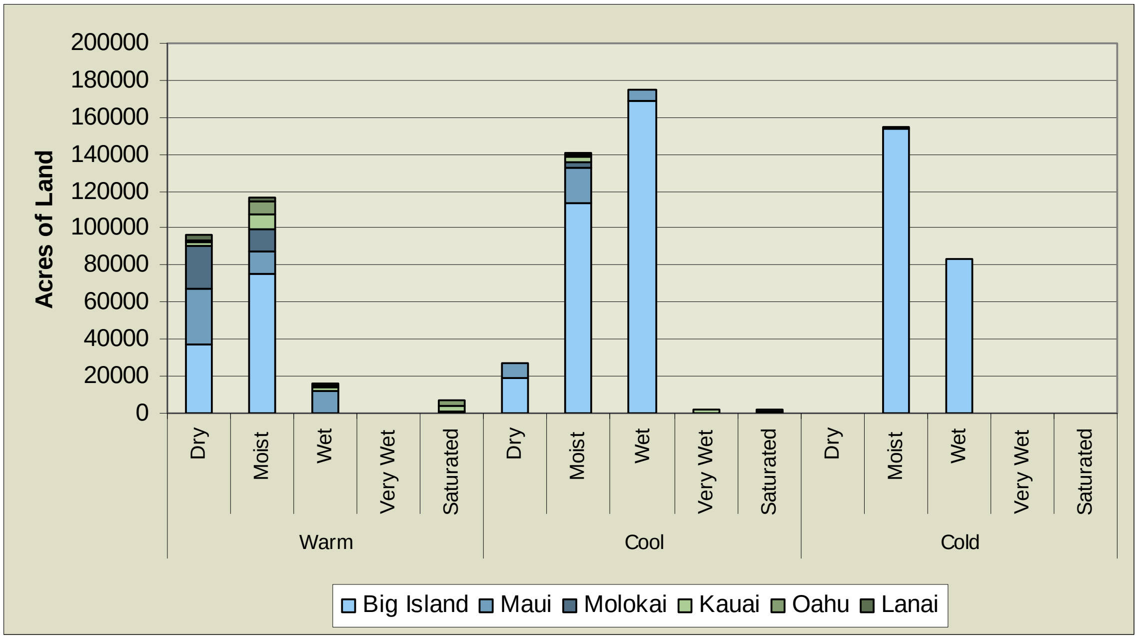

Figure 5-1. State of Hawai'i Non-Irrigated Land Availability by Soil Type and Island

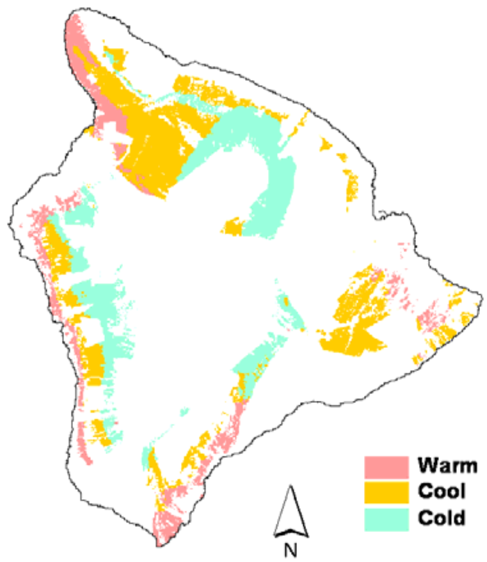

Figure 5-2. Soil Temperature Regimes, Nonprime on the Island of Hawai'i

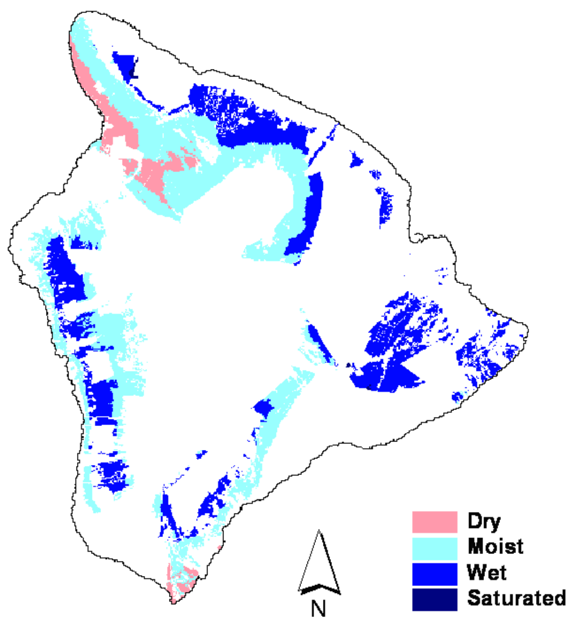

Figure 5-3. Soil Moisture Regimes, Nonprime on the Island of Hawai'i

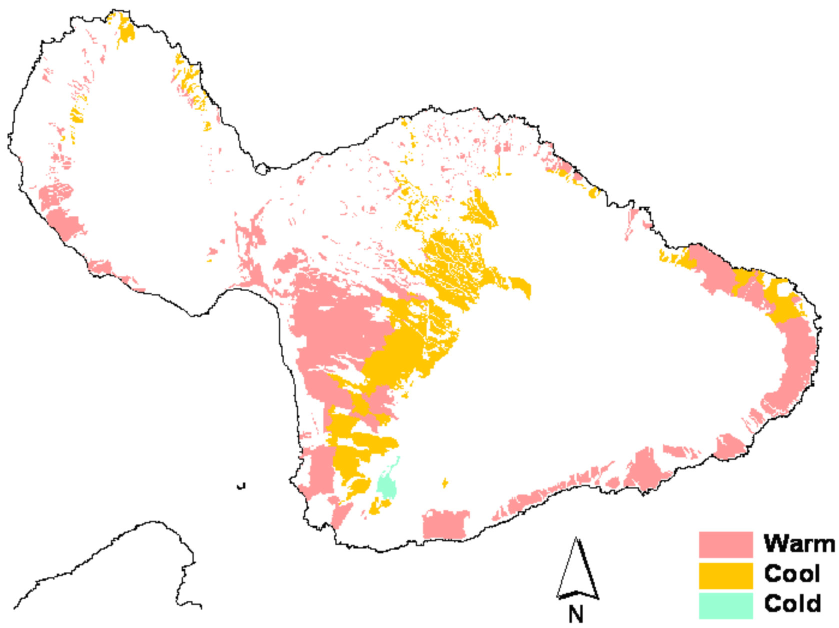

Figure 5-4. Soil Temperature Regimes, Nonprime on the Island of Maui

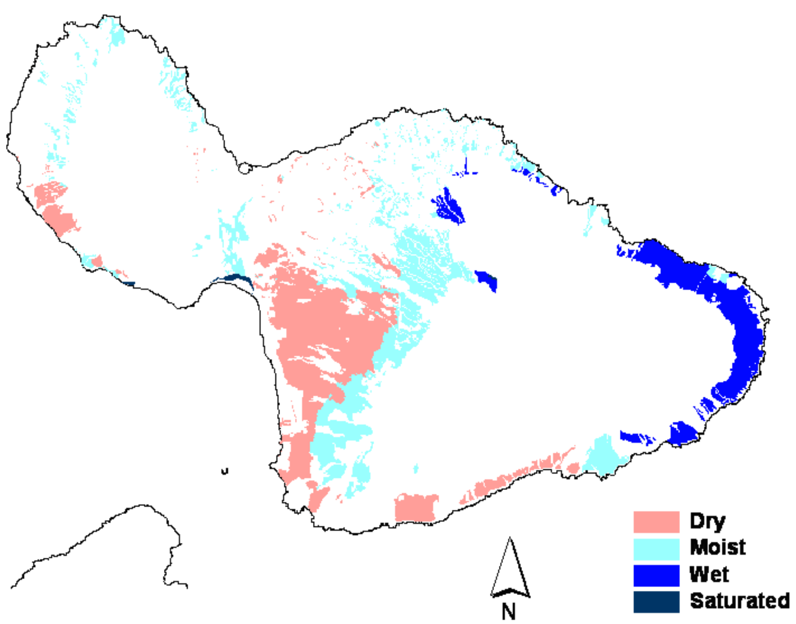

Figure 5-5. Soil Moisture Regimes, Nonprime on the Island of Maui

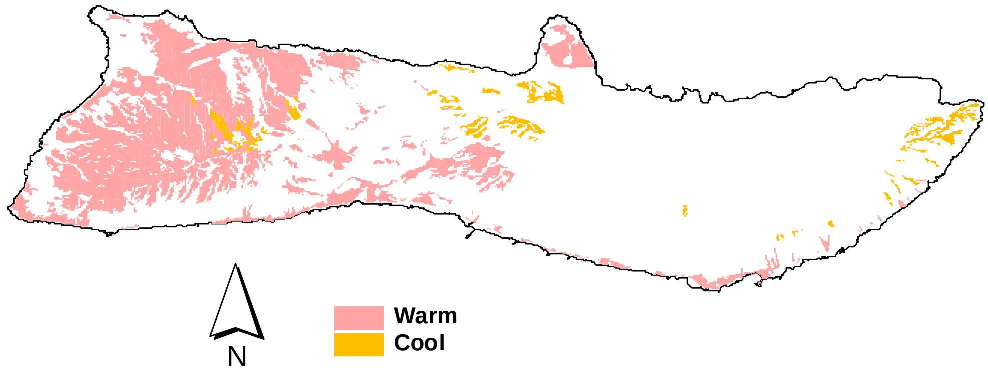

Figure 5-6. Soil Temperature Regimes, Nonprime on the Island of Molokai

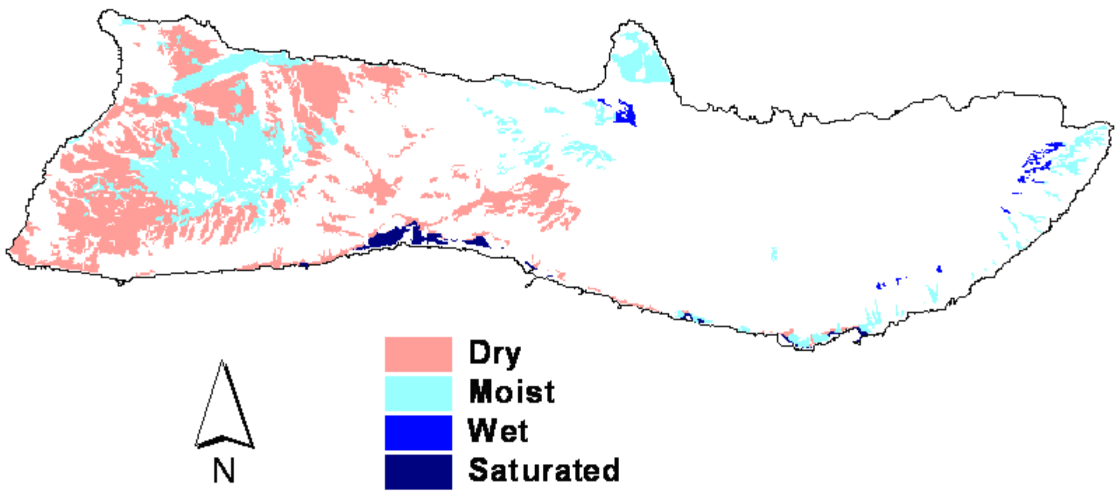

Figure 5-7. Soil Moisture Regimes, Nonprime on the Island of Molokai

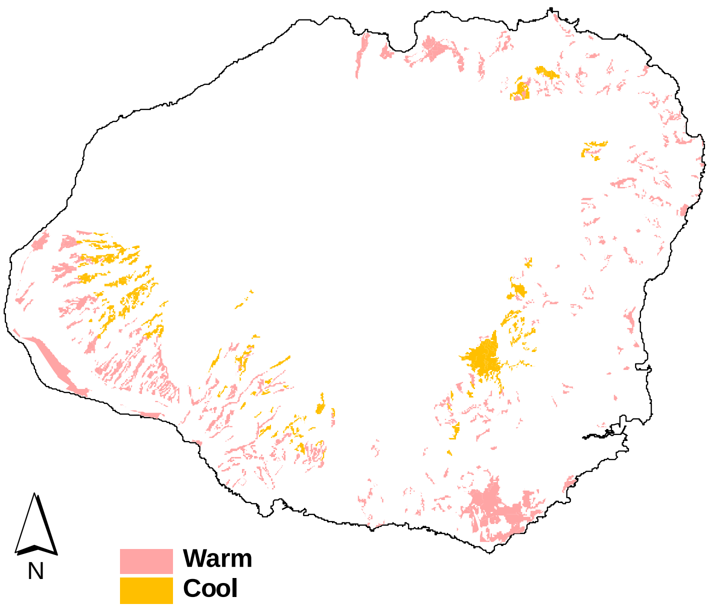

Figure 5-8. Soil Temperature Regimes, Nonprime on the Island of Kauai

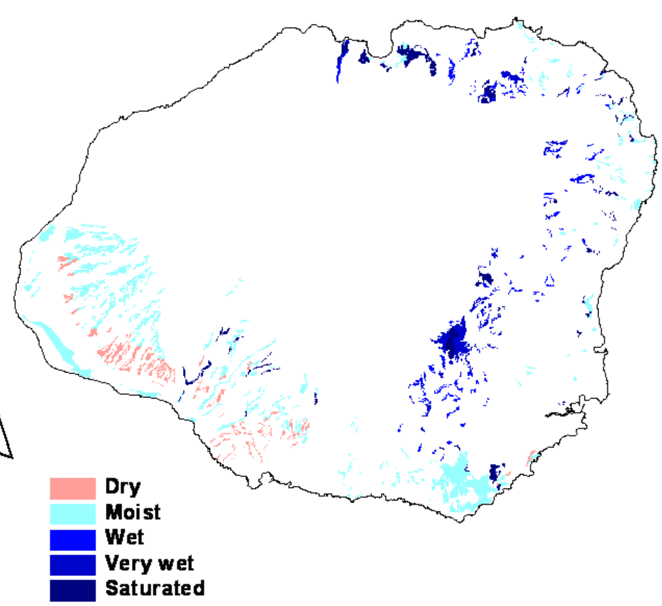

Figure 5-9. Soil Moisture Regimes, Nonprime on the Island of Kauai

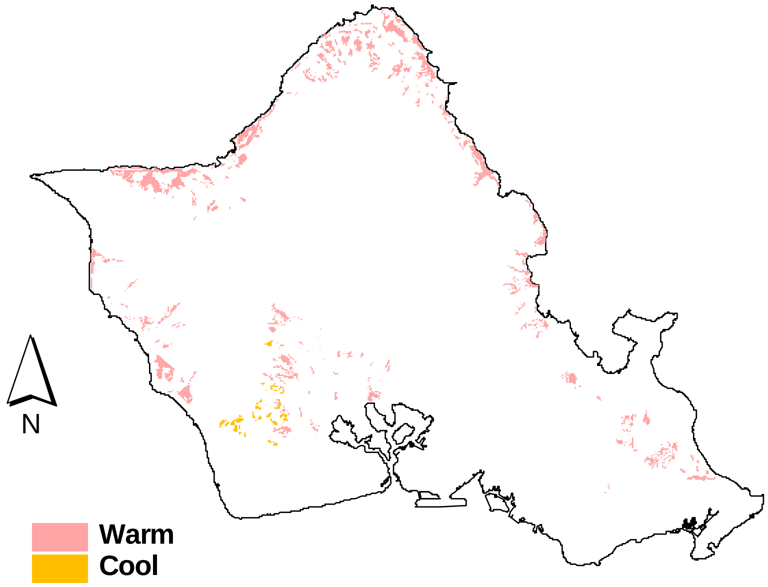

Figure 5-10. Soil Temperature Regimes, Nonprime on the Island of Oahu

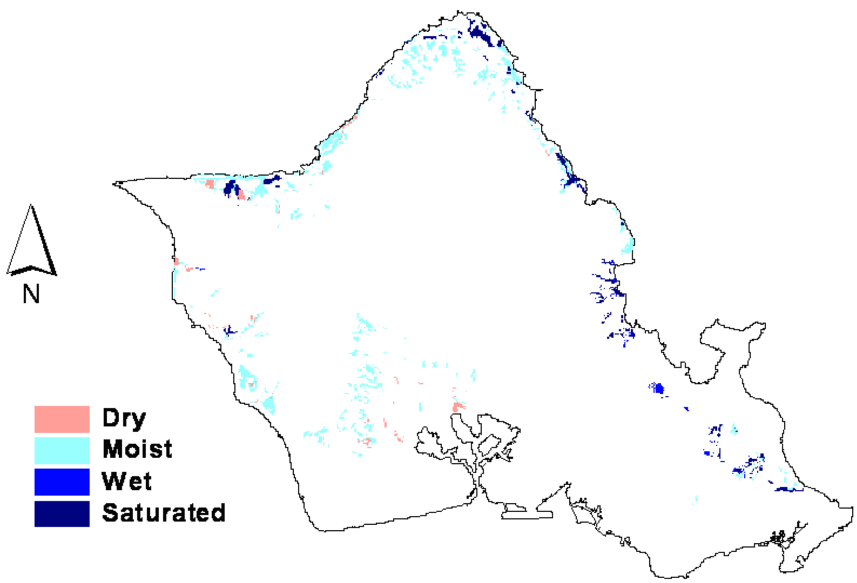

Figure 5-11. Soil Moisture Regimes, Nonprime on the Island of Oahu

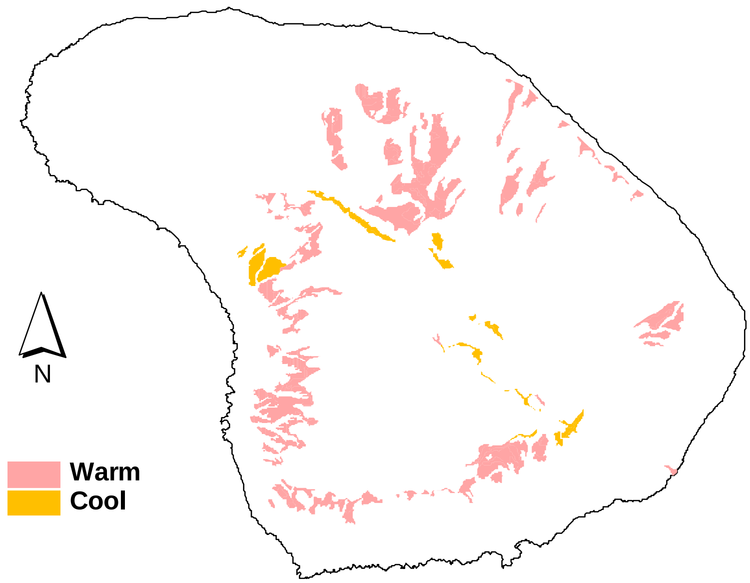

Figure 5-12. Soil Temperature Regimes, Nonprime on the Island of Lanai

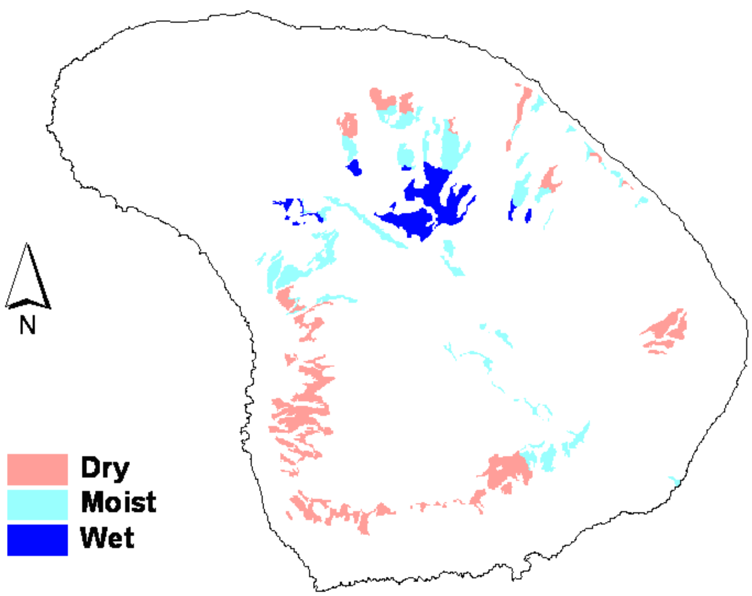

Figure 5-13. Soil Moisture Regimes, Nonprime on the Island of Lanai

Table 5-1. Soil Temperature and Moisture Regimes, Nonprime Agricultural Land

Temp	Moisture	Nonprime Agricultural Land Area (acres)						
		Hawai'i	Maui	Molokai	Kauai	Oahu	Lanai	Total
Warm	Dry	37,071	30,649	22,347	2,470	915	3,020	93,452
	Moist	74,973	12,797	11,611	7,932	7,298	1,585	114,611
	Wet	0	12,093	0	2,074	467	1,181	14,634
	Very wet							
	Saturated	0	472	997	2,230	2,947	0	6,646
	subtotal:	**112,044**	**56,011**	**34,955**	**14,706**	**11,627**	**5,786**	**229,343**
Cool	Dry	19,216	8,350	0	0	0	0	27,566
	Moist	113,162	19,819	2,897	3,067	692	789	139,637
	Wet	169,318	5,305	640	30	0	0	175,293
	Very wet	0	0	0	2,023	0	0	2,023
	Saturated	1,502	49	0	642	0	0	2,193
	subtotal:	**303,198**	**33,523**	**3,537**	**5,762**	**692**	**789**	**346,712**
Cold	Dry							
	Moist	153,816	852	0	0	0	0	154,668
	Wet	83,778	0	0	0	0	0	83,778
	Very wet							
	Saturated							
	subtotal:	**237,594**	**852**	**0**	**0**	**0**	**0**	**238,446**
Total		**652,836**	**90,386**	**38,492**	**20,468**	**12,319**	**6,575**	**814,501**

Note: Shaded cells are regimes that do not exist on the nonprime agricultural lands.

Irrigation does not seem feasible for the majority of these lands, since the distances between the irrigation ditches and the evaluated crop land suggests that irrigation is not readily available (Figure 5-14). The topography of the islands will further create issues in developing new irrigation to these lands. Biofuel crop production will therefore likely rely on rainfall.

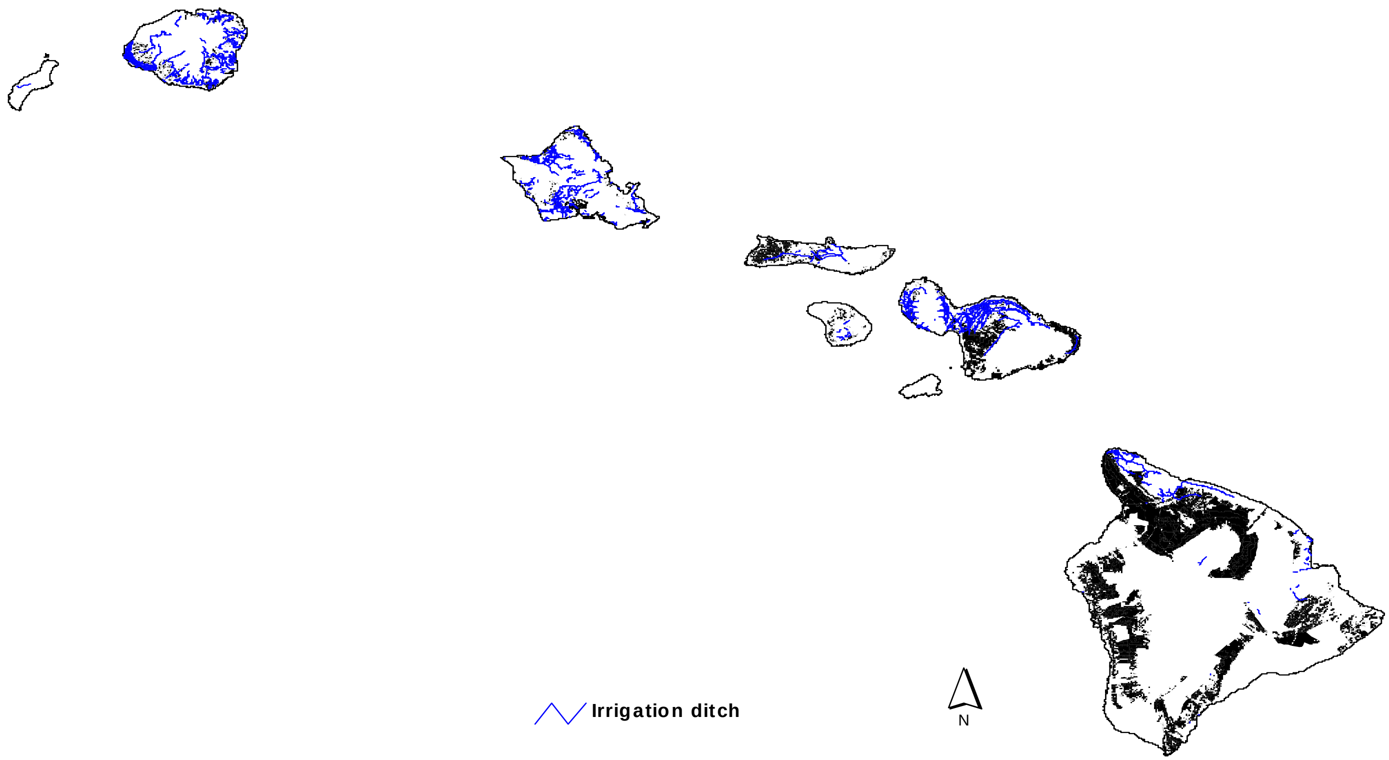

Figure 5-14. Location of Irrigation Ditches and Nonprime Agricultural Lands

(The lands that may be used for biofuel crop production are shaded black and irrigation ditches are blue lines.)

5.1.1 Estimating Biofuel Crop Yield

The crops considered for biofuel production represent sugar, fiber, and oil feedstocks. Sugarcane (*Saccharum officinarum*) produces sugar feedstock. Banagrass (*Pennisetum purpureum*), miscanthus (*Miscanthus x giganteus*), Eucalyptus (*Eucalyptus spp.*), and Leucaena (*Leucaena leucocephala*) produce fiber feedstock. Oil Palm (*Elaeis guineensis*) and Jatropha (*Jatropha curcas*) produce oil.

To estimate the yield of these crops, published reports were obtained. As much as possible, data generated from Hawai'i was collected. The location where the data was produced was classified according to the temperature and moisture regimes defined by NRCS. The yield data were matched to the analogous environment in Hawai'i.

Sugarcane is an irrigated crop in Hawai'i. However, since irrigation may not be available for certain types of lands, it was assumed in this section that sugarcane depended on rainfall for its water requirement. Rainfed sugarcane yield is not readily available, making it necessary to obtain yield data overseas. The sugarcane yield data reported are based on 1 year cane and not the 2 year cane normally produced in Hawai'i.

The following sources of data were used to estimate yields for the crops:

- Sugarcane: FAO, 2003; Government of Fiji and FAO, 1997
- Banagrass: Vincente-Chandler et al., 1962; Vincente-Chandler et al., 1959; Watkins and Lewy-Van Severin, 1951; Paterson, 1935; Wilsie et al., 1940; Paterson, 1933.
- Eucalyptus: Kinoshita and Zhou, 1999; Austin et al., 1997; Stape et al., 2004; Whitesell et al., 1992; DeBell et al., 1997; Skolmen, 1986; Binkley and Ryan, 1998.
- Leucaena: Glover, 1988; Kinoshita and Zhou, 1999; Sun, 1996; Shi, 2003; Austin et al., 1997.
- Oil Palm: Papademetriou and Dent, 2001; Hai, 2000; Udom, 2002; Kallarackal et al., 2004; Oil World Annual 2004.
- Jatropha: Heller, 1996; Foidl et al., 1996; Benge; Ishii and Takeuchi, 1987; Wiesenhutter, 2003.

Miscanthus is currently being cultivated in Europe for use as an energy crop. Miscanthus has also been investigated by institutions in the U.S. such as the University of Illinois. However, no data generated from the tropics were found. Therefore, miscanthus will be excluded from further analysis because of the uncertainty of the applicability of yield data from temperate climates to the tropics. Yields for the other biofuel crops are summarized in Table 5-2. Results of interest from the studies include the following:

- Sugarcane yields more biomass than Banagrass. However, when considering the range of yields, Banagrass may have a greater yield potential than sugarcane. A side-by-side test under rainfed conditions would be needed to resolve this issue.
- Eucalyptus and Leucaena yield well under different conditions. In the warm-moist environment, Leucaena produces more biomass than Eucalyptus. However, Eucalyptus will yield more in a wetter or cooler environment.
- Oil Palm produces nearly 400 gallons of oil/acre/year in a warm-wet environment. But, the yield drops significantly in drier conditions. Jatropha does not produce as much oil, but the range in yields seems to indicate that Jatropha has the potential to yield well in the moist regime. The large range in yields also indicates that care must be taken when growing Jatropha.
- In general, sugarcane, the oil crops, and Leucaena yield well only in the warm environments. In contrast, fiber yields from Banagrass and Eucalyptus are relatively high even in colder environments. However, because of incomplete data, an accurate description of how well these crops yield in all temperature and moisture classes is not defined.

Table 5-3 through Table 5-6 show the yield of each major non-irrigated crop by island and by soil type. Sugarcane cane and Leucaena dry matter production is estimated to be 3.2 and 1.2 million tons/year, respectively. Oil Palm and Jatropha oil production is estimated to be 32.4 and 16.1 million gallons/year in the same regions. Banagrass and Eucalyptus produce more fiber because their production ranges into the cooler regions, about 3.70 and 3.63 million tons/year.

Table 5-2. Rainfed Dry Matter and Oil Yield of Crops

Temp	Moisture	Sugarcane (ton/acre/ year)	Banagrass (ton/acre/ year)	Eucalyptus (ton/acre/ year)	Leucaena (ton/acre/ year)	Oil Palm (gallons/ acre/year)	Jatropha (gallons/ acre/year)
Warm	Dry						
	Moist	23.8 (19.4-28.3)	21.5 (8.7-38.0)	7.8 (6.7-10.7)	8.8 (1.2-19.3)	226 (119-298)	114 (29-381)
	Wet	28.6 (24.1-34.0)	26.8 (15.2-38.3)	11.0 (9.0-13.0)	8.0 (5.4-10.5)	390 (262-500)	180 (48-286)
	Very wet						
	Saturated		14.1 (6.4-21.8)				
Cool	Dry						
	Moist						
	Wet			9.9 (7.5-12.0)			
	Very wet						
	Saturated						
Cold	Dry						
	Moist						
	Wet		8.2 ()	9.7 (9.1-10.2)	2 (0.0-6.6)		
	Very wet						
	Saturated						

Note: Values are averages and values in parentheses are ranges of the yield observed in analogous environments in Hawai'i or other locations. Blank cells have no data reported for regimes. Shaded cells are regimes that do not apply to the partitioned lands in Hawai'i that may produce biofuel feedstock crops.

Table 5-3. Rainfed Sugarcane Cane Production in Nonprime Agricultural Lands

		Production of Sugarcane (thousand tons cane/year)					
Temp	**Moisture**	**Hawai'i**	**Maui**	**Molokai**	**Kauai**	**Oahu**	**Lanai**
Warm	Dry						
	Moist	1780 (1450-2120)	305 (111-362)	276 (225-329)	189 (154-224)	174 (142-207)	38 (31-45)
	Wet		346 (291-411)		59 (50-71)	13 (11-16)	34 (28-40)
	Very wet						
	Saturated						
Cool	Dry						
	Moist						
	Wet						
	Very wet						
	Saturated						
Cold	Dry						
	Moist						
	Wet						
	Very wet						
	Saturated						

Note: Values in parentheses are ranges of production based on yield ranges. Blank cells indicate that a production estimate cannot be made because yield data are not available for those temperature and moisture conditions. Shaded cells are temperature and moisture conditions that are not present in nonprime agricultural lands.

Table 5-4. Rainfed Banagrass Production in Nonprime Agricultural Lands

Temp	Moisture	Production of Banagrass (thousand tons dry matter/year)					
		Hawai'i	Maui	Molokai	Kauai	Oahu	Lanai
Warm	Dry						
	Moist	1,610 (652-2,850)	275 (111-486)	250 (101-441)	171 (69.0-301)	157 (63.5-277)	34.1 (13.8-60.2)
	Wet	0	324 (184-463)	0	55.5 (31.5-79.4)	12.5 (7.10-17.9)	31.7 (18.0-45.2)
	Very wet						
	Saturated	0	6.65 (3.02-10.2)	14.1 (6.38-21.7)	31.4 (14.3-45.2)	41.6 (18.9-64.2)	0
Cool	Dry						
	Moist						
	Wet						
	Very wet						
	Saturated						
Cold	Dry						
	Moist						
	Wet	687 ()	0	0	0	0	0
	Very wet						
	Saturated						

Note: Values in parentheses are ranges of production based on yield ranges. Blank cells indicate that a production estimate cannot be made because yield data are not available for those soil temperature and moisture conditions. Shaded cells are temperature and moisture regimes that are not present in nonprime agricultural lands.

Table 5-5. Rainfed Eucalyptus Production in Nonprime Agricultural Lands

Temp	Moisture	Production of Eucalyptus (thousand tons dry matter/year)					
		Hawai'i	Maui	Molokai	Kauai	Oahu	Lanai
Warm	Dry						
	Moist	585 (502-802)	100 (85.7-137)	90.5 (77.8-124)	61.9 (53.1-84.9)	56.9 (48.9-78.1)	12.4 (10.6-17.0)
	Wet	0	133 (109-157)	0	22.8 (18.7-27.0)	5.14 (4.20-6.07)	13.0 (10.6-15.4)
	Very wet						
	Saturated						
Cool	Dry						
	Moist						
	Wet	1,680 (1,270-2,030)	52.5 (39.8-63.7)	6.33 (4.80-7.68)	0.030 (0.023-0.036)	0	0
	Very wet						
	Saturated						
Cold	Dry						
	Moist						
	Wet	813 (762-855)	0	0	0	0	0
	Very wet						
	Saturated						

Note: Values in parentheses are ranges of production based on yield ranges. Blank cells indicate that a production estimate cannot be made because yield data are not available for those temperature and moisture regimes. Shaded cells are temperature and moisture conditions that are not present in nonprime agricultural lands.

Table 5-6. Rainfed Leucaena Production in Nonprime Agricultural Lands

Temp	Moisture	Production of Leucaena (thousand tons dry matter/year)					
		Hawai'i	Maui	Molokai	Kauai	Oahu	Lanai
Warm	Dry						
	Moist	660 (90.0-1,450)	113 (15.4-247)	102 (13.9-224)	69.8 (9.52-153)	64.2 (8.76-141)	13.9 (1.90-30.6)
	Wet	0	96.7 (65.3-127)	92.7 (62.7-122)	16.6 (11.2-21.7)	3.74 (2.52-4.90)	9.45 (6.38-12.4)
	Very wet						
	Saturated						
Cool	Dry						
	Moist						
	Wet						
	Very wet						
	Saturated						
Cold	Dry						
	Moist						
	Wet	168 (0.0-553)	0	0	0	0	0
	Very wet						
	Saturated						

Note: Values in parentheses are ranges of production based on yield ranges. Blank cells indicate that a production estimate cannot be made because yield data are not available for those temperature and moisture regimes. Shaded cells are temperature and moisture conditions that are not present in nonprime agricultural lands.

Table 5-7. Rainfed Oil Palm Oil Production in Nonprime Agricultural Lands							
		Oil Production from Oil Palm (million gallons/year)					
Temp	**Moisture**	**Hawai'i**	**Maui**	**Molokai**	**Kauai**	**Oahu**	**Lanai**
Warm	Dry						
	Moist	16.9 (8.92-22.3)	2.89 (1.52-3.81)	2.62 (1.38-3.46)	1.79 (0.944-2.36)	1.65 (0.868-2.17)	0.358 (0.046-0.472)
	Wet	0	4.72 (3.17-6.05)	0	0.809 (0.543-1.04)	0.182 (0.122-0.234)	0.461 (0.309-0.591)
	Very wet						
	Saturated						
Cool	Dry						
	Moist						
	Wet						
	Very wet						
	Saturated						
Cold	Dry						
	Moist						
	Wet						
	Very wet						
	Saturated						

Note: Values in parentheses are ranges of production based on yield ranges. Blank cells indicate that a production estimate cannot be made because yield data are not available for those temperature and moisture regimes. Shaded cells are temperature and moisture conditions that are not present in nonprime agricultural lands.

Table 5-8. Rainfed Jatropha Oil Production in Nonprime Agricultural Lands

Temp	Moisture	Oil Production from Jatropha (million gallons/year)					
		Hawai'i	Maui	Molokai	Kauai	Oahu	Lanai
Warm	Dry						
	Moist	8.55 (2.17-28.6)	1.46 (0.371-4.88)	1.32 (0.337-4.42)	0.904 (0.230-3.02)	0.832 (0.212-2.78)	0.181 (0.046-0.604)
	Wet	0	2.18 (0.580-3.46)	0	0.373 (0.100-0.593)	0.084 (0.022-0.134)	0.213 (0.057-0.338)
	Very wet						
	Saturated						
Cool	Dry						
	Moist						
	Wet						
	Very wet						
	Saturated						
Cold	Dry						
	Moist						
	Wet						
	Very wet						
	Saturated						

Note: Values in parentheses are ranges of production based on yield ranges. Blank cells indicate that a production estimate cannot be made because yield data are not available for those temperature and moisture regimes. Shaded cells are temperature and moisture conditions that are not present in nonprime agricultural lands.

A summary of the total biomass potential for ethanol and biodiesel production by crop type and island can be seen in Figure 5-15 and Figure 5-16. With most of the available land on the Big Island, yields from the Big Island dominate both figures.

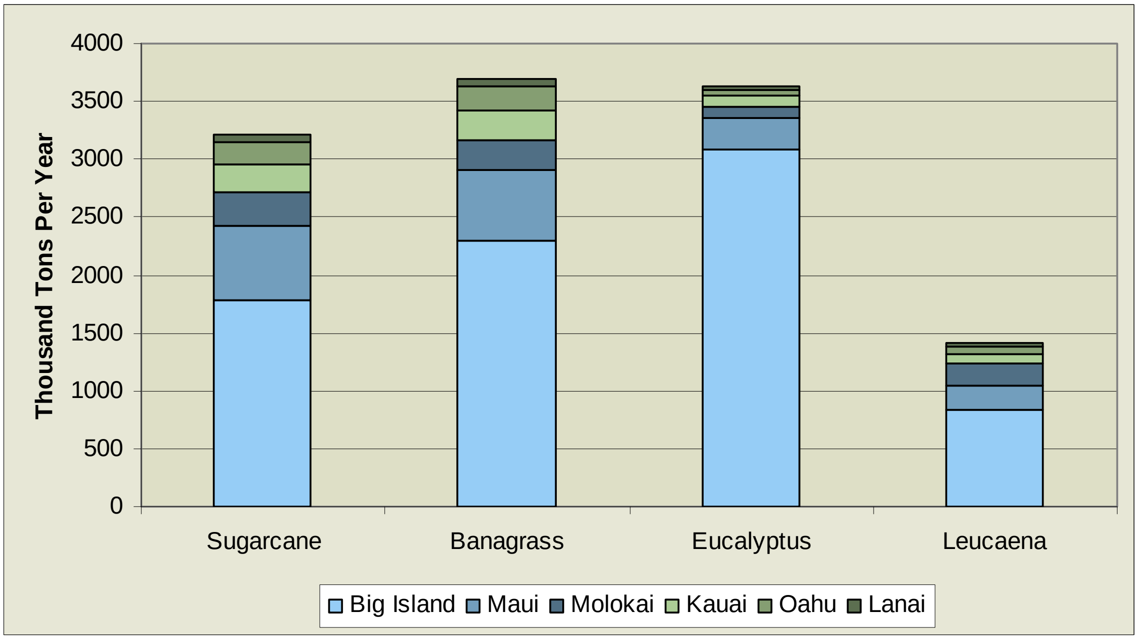

Figure 5-15. Biomass Potential by Crop Type and Island, Nonprime Ethanol.

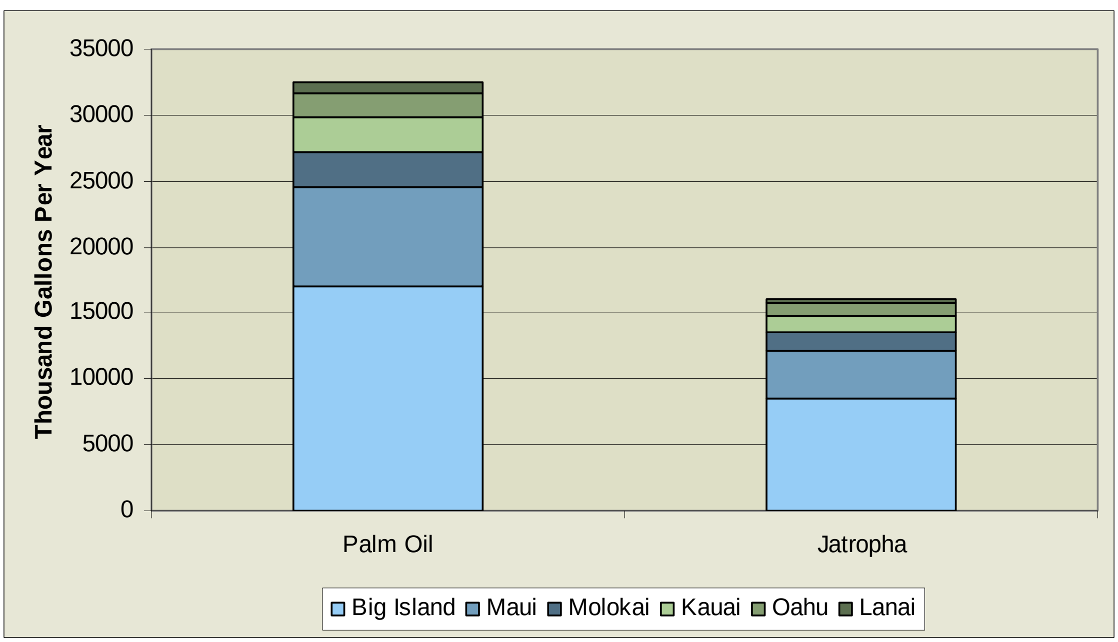

Figure 5-16. Biomass Potential by Crop Type and Island, Nonprime Biodiesel.

The use of production machinery for the sugar and fiber feedstock crops is well known and exists today. Sugarcane is in production in Hawai'i and similar equipment can be used for its production as a biofuel crop. Forage harvesters were used to harvest Banagrass on Molokai as a demonstration plot (Osgood et al., 1996). Mechanical harvesting of Eucalyptus and Leucaena has been demonstrated in Hawai'i as well (Whitesell et al., 1992; Brewbaker, 1980).

There are no mechanized harvesters for the oil crops. Oil Palm fruit bunches are hand harvested in countries where it is grown. Harvesting has been semi-mechanized with power cutters and cherry-picker type lifts, but not fully mechanized. Harvesting of Jatropha is manual. Modifying nut harvesters has been proposed to collect Jatropha fruit, but there are no mechanical harvesters on the market yet. Therefore, the yields of these crops will be somewhat lower than for fiber crops.

For perspective, the sugar, fiber, and oil production from non-irrigated lands would not be sufficient to fulfill the entire fuel needs of the State of Hawai'i. In 2005, Hawai'i consumed 307 million gallons of diesel and 461 million gallons of gasoline. The 32.4 million gallons of oil from Oil Palm could be converted to about 29.2 million gallons of biodiesel, or about 9.5 percent of diesel consumption in 2005. Fiber from the Banagrass (3.7 million tons) could be converted to 247.9 million gallons of ethanol using a conversion factor of 67 gallons ethanol/ton of biomass. This would be equivalent to 173.5 million gallons of gasoline, or 38 percent of gasoline consumption in 2005. While these fuel production estimates are significant in quantity, it is not sufficient to supply Hawaii's current fuel needs. However, this level of production would meet the needs of Act 240 and displace a large amount of imported petroleum. If greater displacement is desired, the use of prime agricultural land for energy crops would need to be considered.

5.1.2 Recommendations for Non-irrigated Energy Crops

Improvements in the yield of ethanol from cellulosic sources could increase the total generation potential of the state of Hawai'i. If the yield improves from 67 to 80 gallons per ton, the analysis projects that Hawai'i could produce 445 million gallons per year of ethanol from Eucalyptus and Banagrass planted in non-irrigated lands in Hawai'i. Figure 5-17 shows the breakdown of potential by island.

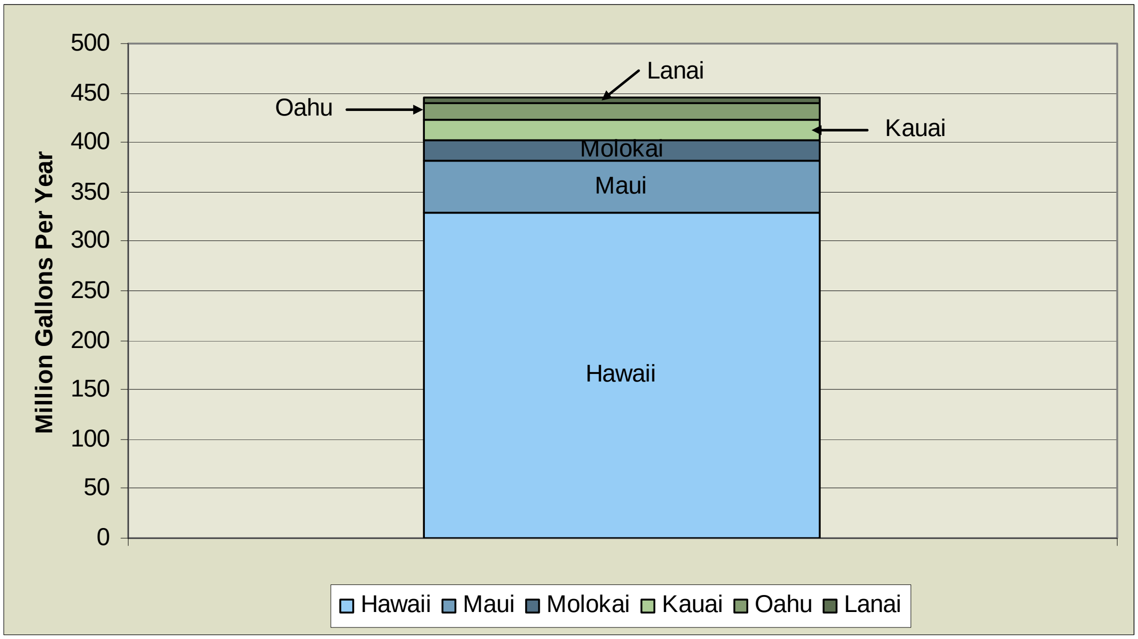

Figure 5-17. Non-Irrigated Crop Ethanol Potential, By Island (80 gallons/ton).

Table 5-3 through Table 5-8 show that land having cool and cold temperature regimes would not be fully utilized. Many of the proposed crops perform well only in the warm regions (129,000 acres) leaving the colder regions unused (585,000 acres). Careful study on how to better utilize these lands needs to be done. Agriculturally zoned land borders conservation lands in the upper elevations where the cold regime is located. Balancing the need for fuel and preservation of native forests or sensitive ecosystems will require new approaches to biofuel feedstock production. A possible approach would be to identify fast-growing indigenous forest species that could produce fiber for biofuel production.

Increasing production in the low elevation lands may be possible as well. Extending production into pahoehoe lava lands within the agriculturally zoned lands on the island of Hawai'i would add 137,000 acres into production. Some of this pahoehoe land supports the growth of volunteer trees. Practices to better manage this type of land could be a large boost to biofuel production.

Improving yield by selecting more drought tolerant crops for the warm-moist regions would raise production. Guinea grass may be better suited to the moist regions of the state. Locally generated yield data that may soon be available would help to estimate the yield of this promising crop.

Another technology that may improve biofuel production in the warm-moist regions is rain harvesting. Capturing rain water and allowing it to infiltrate the soil makes each rainfall event more productive instead of losing it to runoff. This can be especially effective in the moist regions where water can limit crop growth. Rain harvesting methods may be as simple as making low berms along the contour of slopes. Making rain water more effective could increase yield tremendously in a water limited environment.

5.2 Energy Crop Yields on Prime Agricultural Lands

The objective of this section is to provide an estimate of biofuel feedstock crop yields on prime agricultural lands in Hawai'i. The crops are sugarcane (*Saccharum officinarum*), Banagrass (*Pennisetum purpureum*), Eucalyptus (mainly *Eucalyptus grandis*), Leucaena spp., Oil Palm (*Elaeis guineensis*), and Jatropha (*Jatropha curcas*). The same crops considered in the previous section were used for consistency to show the differences in yields and total production.

5.2.1 Methods

Sugar and biomass yields were estimated from experiments conducted in Hawai'i or the tropics. Characteristics of the soil at these experimental locations were used as a basis for transferring these data to prime agricultural lands across the state of Hawai'i, namely soil temperature and moisture.

5.2.1.1 Soil Characteristics and Land Areas

Soil map units and prime agricultural land maps in a geographic information system format were obtained from the Office of Planning, State of Hawai'i (2008). The maps were used to define prime agricultural land boundaries and the soils series. Soil temperature and moisture regimes were obtained from the on-line soil database of the Natural Resource Conservation Service (2008). The same soil temperature (isomesic, isothermic, and isohyperthermic or cold, cool, and warm) and moisture characterizations (aridic, ustic, udic, perudic, and aquic or dry, moist, wet, very wet, and saturated) used in Section 5.1 were applied in this Section. The land areas of each temperature and moisture combination were estimated for the Islands of Hawai'i, Maui, Lanai, Molokai, Oahu, and Kauai. Land areas excluded from the analysis were those classified as beach, fill land, lava, quarry, rocky, cinder pit, dune, rough broken, and slopes greater than 30 percent.

5.2.1.2 Yield Estimation

Irrigated sugarcane yield on soils found throughout the state was estimated by the Soil Conservation Service. The yield data were associated with soil series in which soil temperature and moisture were defined. Cane yield was estimated from sugar yield that was assumed to compose 13 percent of the cane (NASS, 2006).

Irrigated Banagrass yields were estimated from previous research done in Hawai'i and the tropics (Kinoshita and Zhou, 1999; Osgood et al., 1996; Vincente-Chandler et al., 1962; Vincente-Chandler et al., 1959; Watkins and Lewy-Van Severin, 1951; Paterson, 1935; Wilsie et al., 1940; Paterson, 1933).

No irrigated yield data were found for the remaining crops. To mimic irrigated data, rainfed crop yield data were collected and the lowest one-third of data deleted. The remaining yields were used to calculated mean and range. The yield data was taken from the following references:

- Eucalyptus: Kinoshita and Zhou, 1999; Austin et al., 1997; Stape et al., 2004; Whitesell et al., 1992; DeBell et al., 1997; Skolmen, 1986; Binkley and Ryan, 1998.
- Leucaena: Glover, 1988; Kinoshita and Zhou, 1999; Sun, 1996; Shi, 2003; Austin et al., 1997.
- Oil Palm: Papademetriou and Dent, 2001; Hai, 2000; Udom, 2002; Kallarackal et al., 2004; Oil World Annual 2004.
- Jatropha: Heller, 1996; Foidl et al., 1996 ; Benge ; Ishii and Takeuchi, 1987 ; Wiesenhutter, 2003; Ouwens et al., 2007.

The means were then used to extrapolate data to temperature and moisture classes where no data were found. The extrapolation followed the general trend where lower temperature and higher moisture (lower solar radiation) classes resulted in lower yield on an annual basis. Eucalyptus and Oil Palm did not fit this trend.

5.2.2 Results

There is about 300,000 acres of prime agricultural land that has the potential for biofuel feedstock production. Soil temperature and moisture regimes of these lands are shown on Figure 5-2 through Figure 5-13 for each island. Most of the prime agricultural lands are warm or cool temperature regimes and dry to moist. Seventy-four percent of the prime lands are in the warm temperature regime, while forty-seven percent of the lands are in the moist soil regime. A summary breakdown by land type and island can be seen in Figure 5-18. Unlike the non-irrigated land potential, the irrigated land is more evenly distributed throughout the islands.

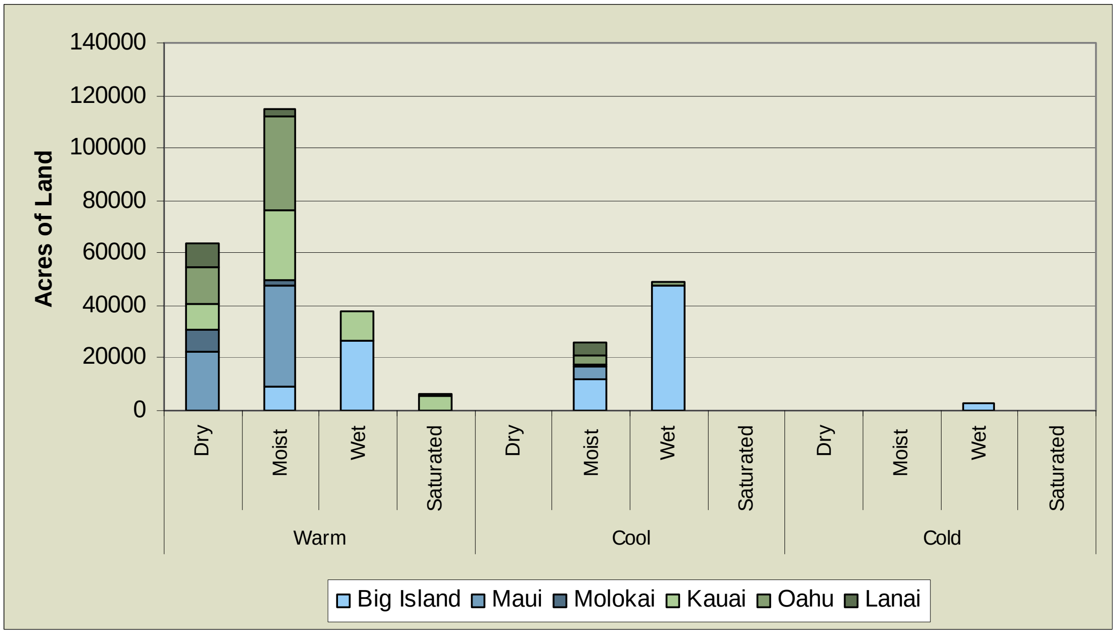

Figure 5-18. State of Hawai'i Irrigate Land Availability by Soil Type and Island.

The predicted yield of crops for the soil temperature and moisture regimes are summarized in Figure 5-19. Key findings include the following:

- In general, the grasses produce more biomass than the trees on an annual basis. However, the yield advantage virtually disappears at the cold temperature regime.
- Eucalyptus out yields Leucaena in the cooler, wetter areas. There are several species of Leucaena, and it was assumed that in the cooler regions of the prime agricultural lands, cold tolerant species or varieties would be planted. Leucaena is a nitrogen-fixer that can be a major advantage in managing the crop's fertilizer regimen.
- Oil Palm produces more oil than Jatropha. Jatropha's characteristic of producing oil seed in dry, marginal soils is no advantage in irrigated, prime agricultural lands.

Production estimates of biomass and oil are given in Table 5-10 through Table 5-16 for each crop. In terms of total biomass production off the entire prime agricultural lands in the state, sugarcane, Banagrass, Eucalyptus, and Leucaena could generate 11.2, 9.4, 2.8, and 3.2 million tons a year. Oil Palm and Jatropha could produce 66 and 62 million gallons of oil a year.

Table 5-9. Land Areas of the Soil Temperature and Moisture Regimes within Prime Agricultural Lands.

Temp	Moisture	Prime Agricultural Land Area (acres)						
		Hawai'i	Maui	Molokai	Kauai	Oahu	Lanai	Total
Warm	Dry	0	22,501	8,177	9,828	14,252	9,153	63,912
	Moist	8,869	38,591	2,312	26,413	36,140	2,345	114,672
	Wet	26,329	0	0	11,135	662	0	38,126
	Saturated	124	119	16	5,344	562	0	6,165
	subtotal:	**35,322**	**61,211**	**10,505**	**52,720**	**51,616**	**11,498**	**222,875**
Cool	Dry	0	77	0	0	0	241	318
	Moist	12,133	4,600	621	207	3,125	5,002	25,687
	Wet	47,669	4	0	71	1,178	0	48,922
	Saturated	36	0	0	21	0	0	57
	subtotal:	**59,838**	**4,681**	**621**	**299**	**4,303**	**5,243**	**74,984**
Cold	Dry							
	Moist	0	1	0	0	0	0	1
	Wet	2,519	0	0	0	0	0	2,519
	Saturated							
	subtotal:	**2,519**	**1**	**0**	**0**	**0**	**0**	**2,520**
Total		**97,679**	**65,893**	**11,126**	**53,020**	**55,919**	**16,741**	**300,378**

Note: Shaded cells are regimes that do not exist on the prime agricultural lands.

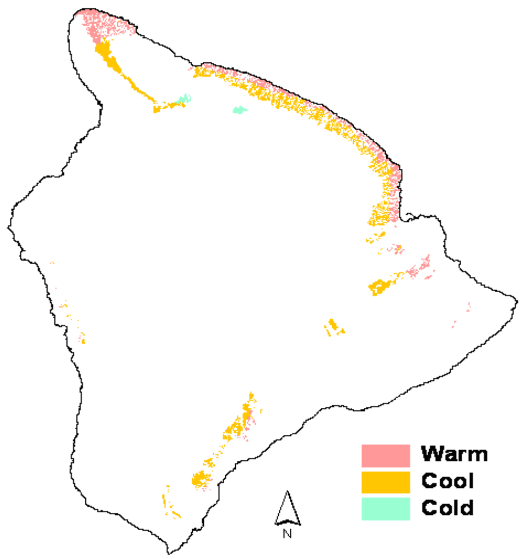

Figure 5-19. Soil Temperature Regimes, Prime Lands on the Island of Hawai'i.

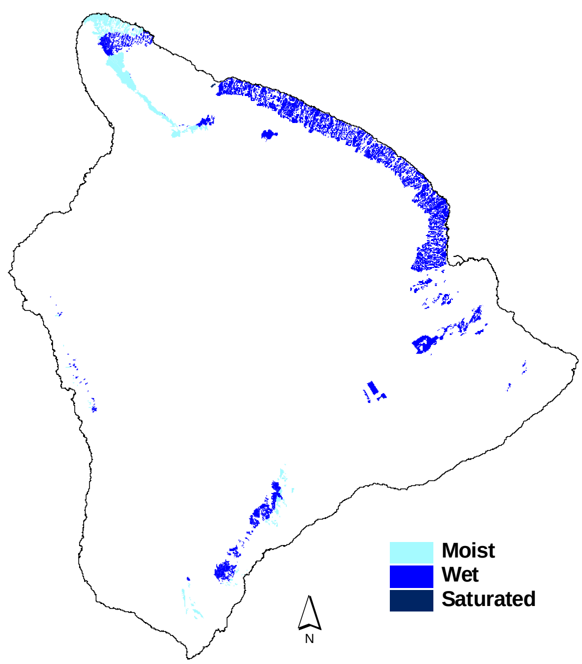

Figure 5-20. Soil Moisture Regimes, Prime Lands on the Island of Hawai'i.

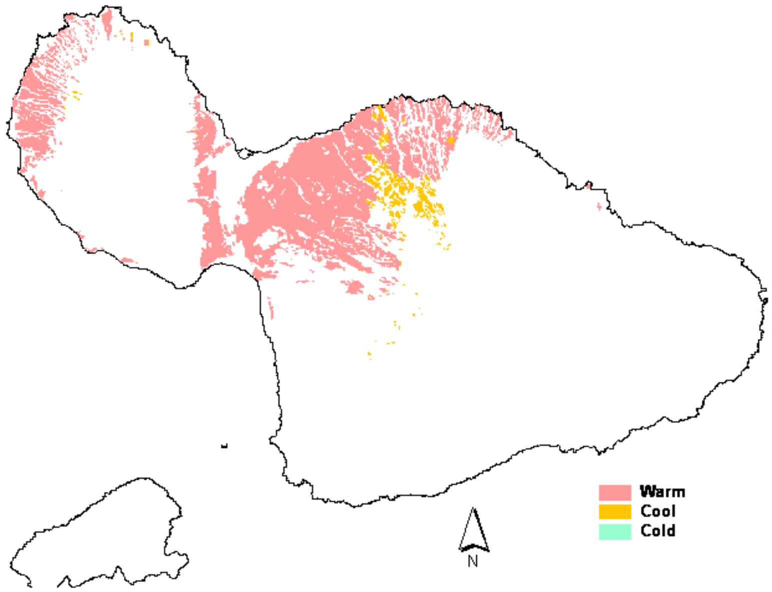

Figure 5-21. Soil Temperature Regimes, Prime Lands on the Island of Maui.

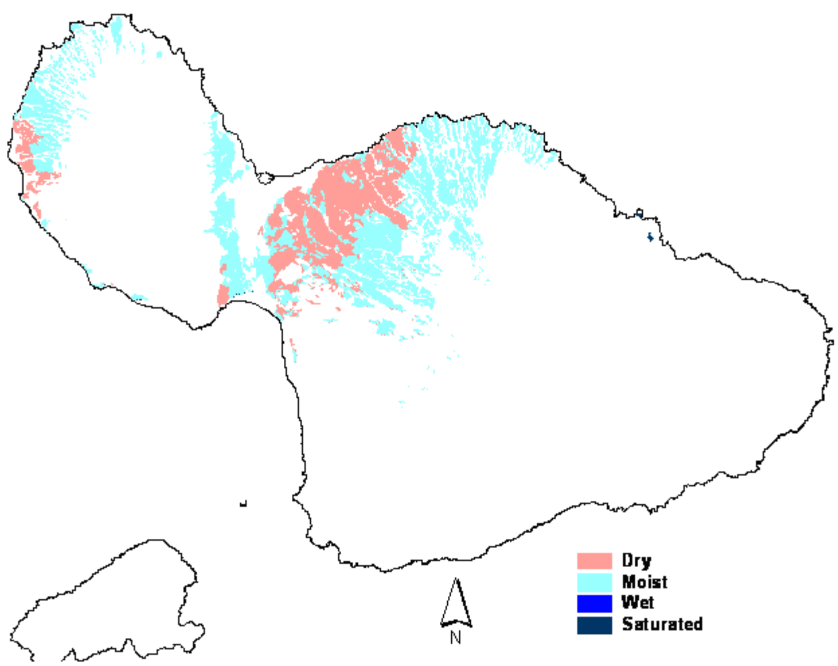

Figure 5-22. Soil Moisture Regimes, Prime Lands on the Island of Maui.

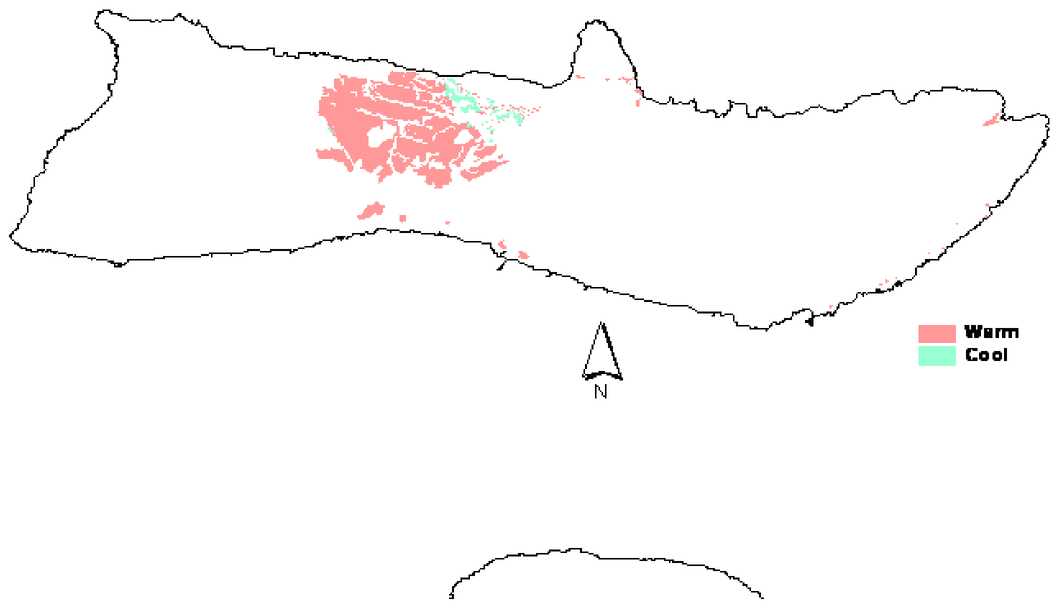

Figure 5-23. Soil Temperature Regimes, Prime Lands on the Island of Molokai.

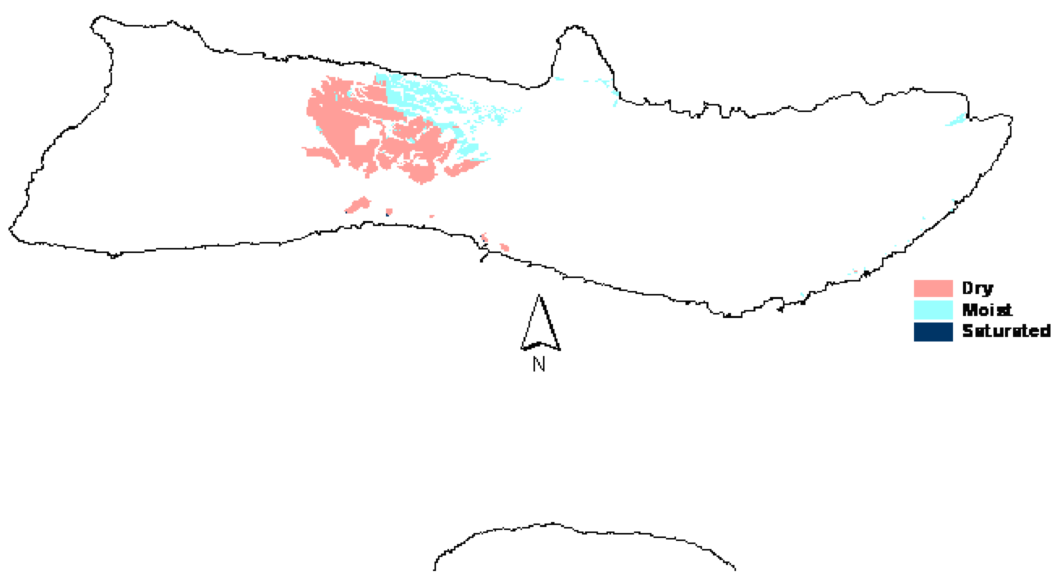

Figure 5-24. Soil Moisture Regimes, Prime Lands on the Island of Molokai.

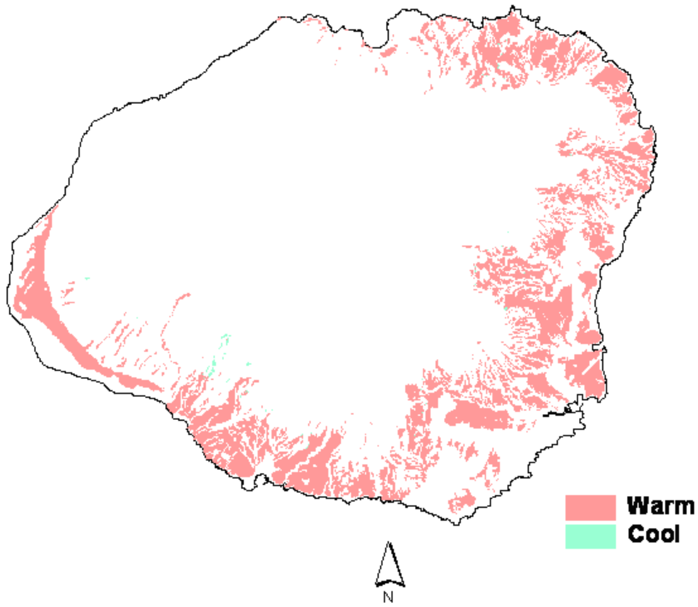

Figure 5-25. Soil Temperature Regimes, Prime Lands on the Island of Kauai.

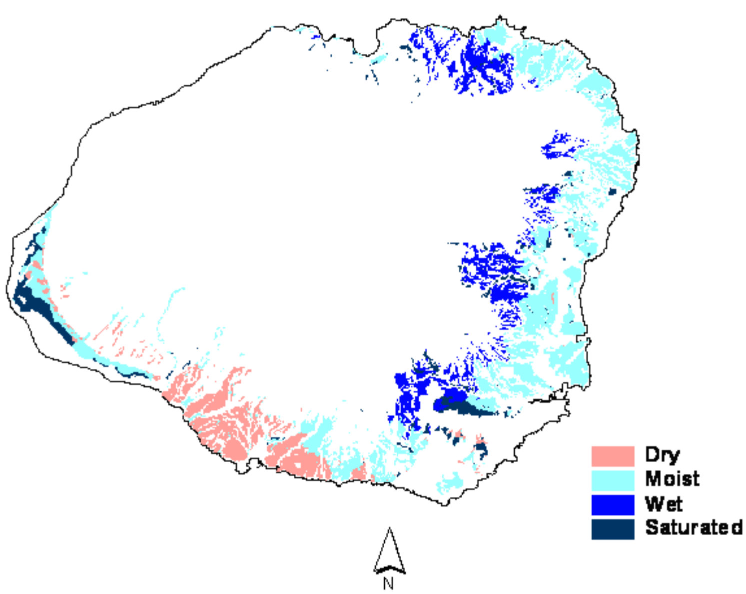

Figure 5-26. Soil Moisture Regimes, Prime Lands on the Island of Kauai.

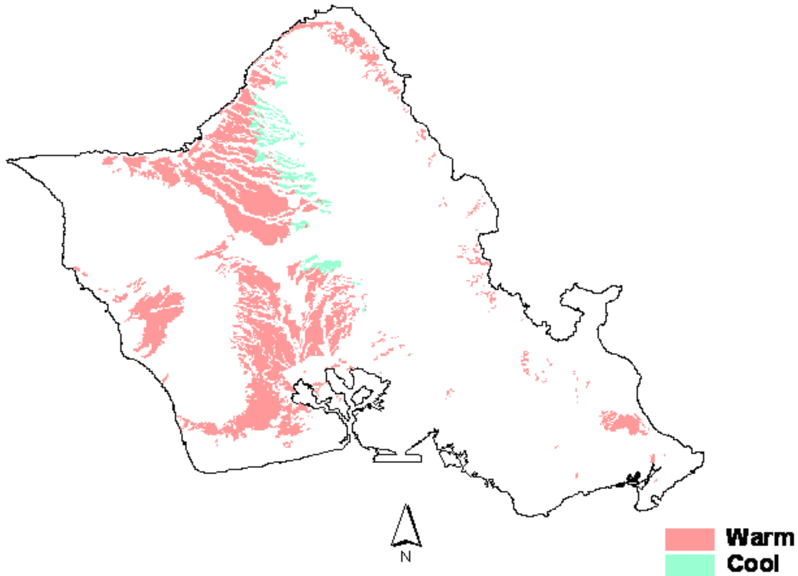

Figure 5-27. Soil Temperature Regimes, Prime Lands on the Island of Oahu.

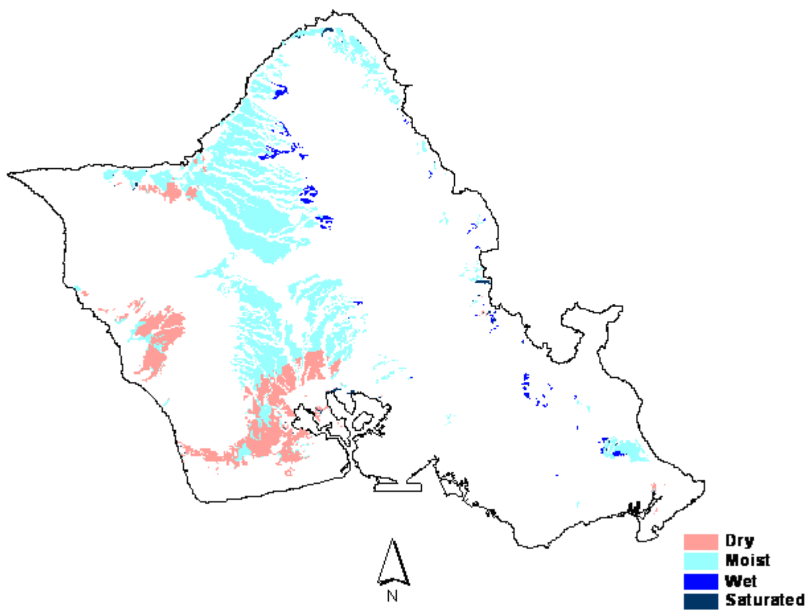

Figure 5-28. Soil Moisture Regimes, Prime Lands on the Island of Oahu.

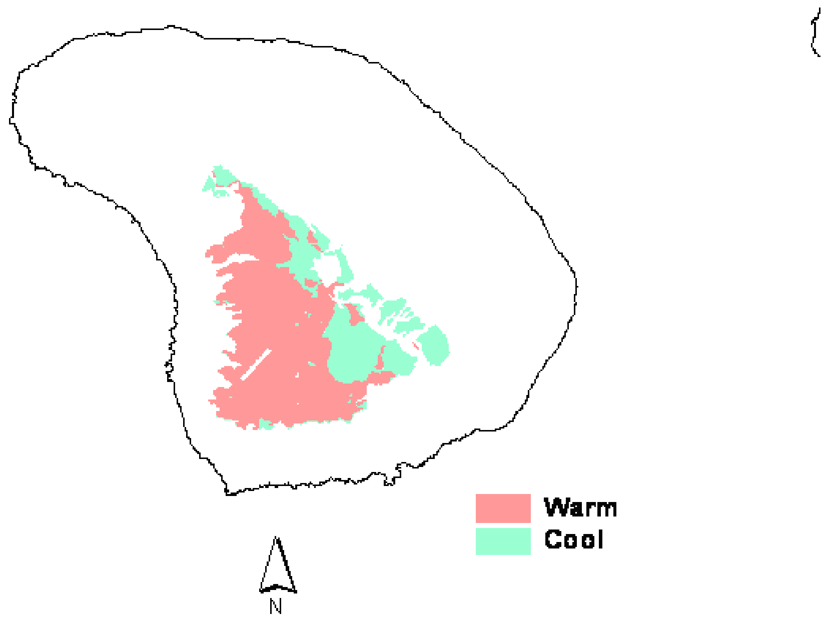

Figure 5-29. Soil Temperature Regimes, Prime Lands on the Island of Lanai.

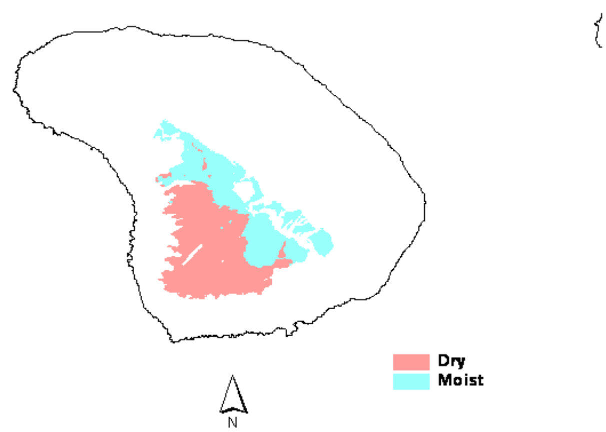

Figure 5-30. Soil Moisture Regimes, Prime Lands on the Island of Lanai.

Table 5-10. Irrigated Dry Matter and Oil Yield of Crops Estimates

Temp	Moisture	Sugarcane (tons/acre/year)	Banagrass (tons/acre/year)	Eucalyptus (tons/acre/year)	Leucaena (tons/acre/year)	Oil Palm (gallons/ acre/year)	Jatropha (gallons/ acre/year)
Warm	Dry	52 (46 - 58)	45 (26 - 67)	8 ( )	13 (10 - 13)	300 ( )	290 ( )
	Moist	52 (46 - 58)	37 (15 - 42)	9 (7 - 11)	12 (8 - 19)	300 ( )	290 ( )
	Wet	35 (31 - 38)	37 ( )	11 (9 - 13)	8 (5 - 11)	433 (362 - 500)	210 ( )
	Saturated		30 ( )	10 ( )	6 ( )		
Cool	Dry	29 (23 - 35)	12 ( )	9 ( )	10 ( )		
	Moist	29 (23 - 35)	10 ( )	10 ( )	9 ( )		
	Wet	19 (15 - 23)	10 ( )	12 (11 - 12)	6 (4 - 7)		
	Saturated		8 ( )	11 ( )	4 ( )		
Cold	Dry						
	Moist	19 (15 – 23)	7 (6 - 7)	8 ( )	7 ( )		
	Wet	13 (10 - 15)	7 ( )	10 ( )	5 ( )		
	Saturated						

Note: Values are averages and values in parentheses are ranges of the yield observed in analogous environments in Hawai'i or other locations. Blank cells have no data to base an extrapolated yield estimate. Shaded cells are regimes that do not apply to the prime agricultural lands in Hawai'i.

Table 5-11. Estimate of Irrigated Sugarcane Cane Production on Prime Agricultural Lands

Temp	Moisture	Production of Sugarcane (thousand tons cane/year)					
		Hawai'i	**Maui**	**Molokai**	**Kauai**	**Oahu**	**Lanai**
Warm	Dry	464 (409 - 512)	1,177 (1,039 - 1,298)	428 (377 - 472)	514 (454 - 567)	745 (658 - 822)	479 (422 - 528)
	Moist	1,377 (1,215 - 1,519)	2,018 (1,781 - 2,226)	121 (107 - 133)	1,382 (1,219 - 1,524)	1,890 (1,668 - 2,085)	123 (108 - 135)
	Wet	4.3 (3.8 - 4.8)			385 (343 - 428)	23 (20 - 25)	
	Saturated						
Cool	Dry		2.3 (1.8 - 2.7)				7.0 (5.6 - 8.3)
	Moist	355 (280 - 420)	134 (106 - 159)	18 (14 - 21)	6.1 (4.8 - 7.2)	91 (72-108)	146 (115 - 173)
	Wet	917 (733 - 1,100)	0.08 (0.06 - 0.09)		1.4 (1.1 - 1.6)	23 (18 - 27)	
	Saturated						
Cold	Dry						
	Moist		0.02 (0.02 - 0.02)				
	Wet	33 (25 - 39)					
	Saturated						

Note: Values in parentheses are ranges of production. Blank cells indicate that a production estimate cannot be made because yield data are not available. Shaded cells are temperature and moisture conditions that are not present in nonprime agricultural lands.

Table 5-12. Estimate of Irrigated Banagrass Production on Prime Agricultural Lands

Temp	Moisture	Production of Biomass (thousand tons/year)					
		Hawai'i	Maui	Molokai	Kauai	Oahu	Lanai
Warm	Dry	399 (231 - 594)	1,013 (585 - 1,508)	368 (213 - 548)	442 (256 - 658)	641 (371 - 955)	412 (238 - 613)
	Moist	974 (395 - 1,106)	1428 (579 - 1,621)	86 (35 - 97)	977 (396 - 1,109)	1,337 (542 - 1,518)	87 (35 - 98)
	Wet	4.6 ( )			412 ( )		
	Saturated		3.6 ( )	0.5 ( )	0.6 ( )		
Cool	Dry		0.9 ( )				2.9 ( )
	Moist	121 ( )	46 ( )		2.1 ( )	31 ( )	50 ( )
	Wet	476 ( )	0.04 ( )		0.7 ( )	12 ( )	
	Saturated	0.3 ( )			0.2 ( )		
Cold	Dry						
	Moist		0.007 ( )				
	Wet	18 ( )					
	Saturated						

Note: Values in parentheses are ranges of production. Blank cells indicate that a production estimate cannot be made because yield data are not available. Shaded cells are temperature and moisture conditions that are not present in nonprime agricultural lands.

Table 5-13. Estimate of Irrigated Eucalyptus Production on Prime Agricultural Lands

		Production of Biomass (thousand tons/year)					
Temp	**Moisture**	**Hawai'i**	**Maui**	**Molokai**	**Kauai**	**Oahu**	**Lanai**
Warm	Dry	71 ( )	180 ( )	65 ( )	79 ( )	114 ( )	73 ( )
	Moist	237 (184 - 290)	347 (270 - 425)	21 (16 - 25)	238 (185 - 291)	325 (253 - 398)	21 (16.26)
	Wet	1.4 (1.1 - 1.6)			122 (100 - 145)	7.3 (6.0-8.6)	
	Saturated		1.2 ( )	0.2 ( )	0.2 ( )	5.6 ( )	
Cool	Dry		0.7 ( )				2.1 ( )
	Moist	121 ( )	46 ( )	6.2 ( )	2.1 ( )	31 ( )	50 ( )
	Wet	572 (524 - 572)	0.05 ( )		0.9 (0.8 - 0.9)	14 (13 - 14)	
	Saturated	0.4 ( )			0.2 ( )		
Cold	Dry						
	Moist		0.01 ( )				
	Wet	25 ( )					
	Saturated						

Note: Values in parentheses are ranges of production. Blank cells indicate that a production estimate cannot be made because yield data are not available. Shaded cells are temperature and moisture conditions that are not present in nonprime agricultural lands.

Table 5-14. Estimate of Irrigated Leucaena Production on Prime Agricultural Lands

		Production of Biomass (thousand tons/year)					
Temp	**Moisture**	**Hawai'i**	**Maui**	**Molokai**	**Kauai**	**Oahu**	**Lanai**
Warm	Dry	115 ( )	293 ( )	106 ( )	128 ( )	185 ( )	119 ( )
	Moist	316 ( )	463 ( )	28 ( )	317 ( )	434 ( )	28 ( )
	Wet	1.0 ( )			89 ( )	5.3 ( )	
	Saturated		0.7 ( )	0.1 ( )	0.1 ( )	3.4 ( )	
Cool	Dry		0.8 ( )				2.4 ( )
	Moist	109 ( )	41 ( )	5.6 ( )	1.9 ( )	28 ( )	45 ( )
	Wet	286 ( )	0.02		0.4 ( )	7.1 ( )	
	Saturated	0.1 ( )	( )		0.01 ( )		
Cold	Dry						
	Moist		0.01				
	Wet	13 ( )	( )				
	Saturated						

Note: Values in parentheses are ranges of production. Blank cells indicate that a production estimate cannot be made because yield data are not available. Shaded cells are temperature and moisture conditions that are not present in nonprime agricultural lands.

Table 5-15. Estimate of Irrigated Oil Palm Production on Prime Agricultural Lands

		Production of Oil (thousand gallons/year)					
Temp	**Moisture**	**Hawai'i**	**Maui**	**Molokai**	**Kauai**	**Oahu**	**Lanai**
Warm	Dry	2,643 ( )	6,705 ( )	2,437 ( )	2,929 ( )	4,247 ( )	2,728 ( )
	Moist	7,846 ( )	11,577 ( )	689 ( )	7,871 ( )	10,770 ( )	699 ( )
	Wet	54 (45 - 62)			4,821 (4,031 - 5,568)	287 (240 - 331)	
	Saturated						
Cool	Dry						
	Moist						
	Wet						
	Saturated						
Cold	Dry						
	Moist						
	Wet						
	Saturated						

Note: Values in parentheses are ranges of production. Blank cells indicate that a production estimate cannot be made because yield data are not available. Shaded cells are temperature and moisture conditions that are not present in nonprime agricultural lands.

Table 5-16. Estimate of Irrigated Jatropha Production on Prime Agricultural Lands

		Production of Oil (thousand gallons/year)					
Temp	**Moisture**	**Hawai'i**	**Maui**	**Molokai**	**Kauai**	**Oahu**	**Lanai**
Warm	Dry	2,572 ( )	6,525 ( )	2,371 ( )	2,850 ( )	4,133 ( )	2,654 ( )
	Moist	7,635 ( )	11,191 ( )	670 ( )	7,660 ( )	10,481 ( )	680 ( )
	Wet	26 ( )			2,338 ( )	139 ( )	
	Saturated						
Cool	Dry						
	Moist						
	Wet						
	Saturated						
Cold	Dry						
	Moist						
	Wet						
	Saturated						

Note: Values in parentheses are ranges of production. Blank cells indicate that a production estimate cannot be made because yield data are not available. Shaded cells are temperature and moisture conditions that are not present in nonprime agricultural lands.

A summary of the total biomass potential for ethanol and biodiesel production by crop type and island can be seen in Figure 5-31 and Figure 5-32. Distribution of resource potential is more even relative to the non-irrigated land. For ethanol production, only sugarcane and Banagrass are impacted by this land type, since the woody crops gain little yield advantage through irrigation. Palm oil production increases by a factor of two with irrigation, while Jatropha oil is expected to more than triple.

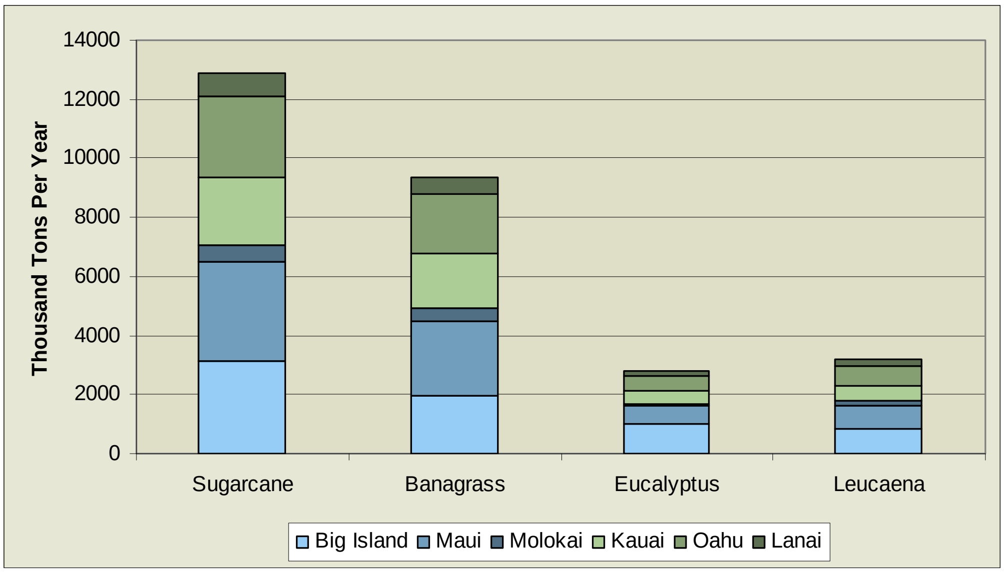

Figure 5-31. Biomass Potential by Crop Type and Island, Ethanol.

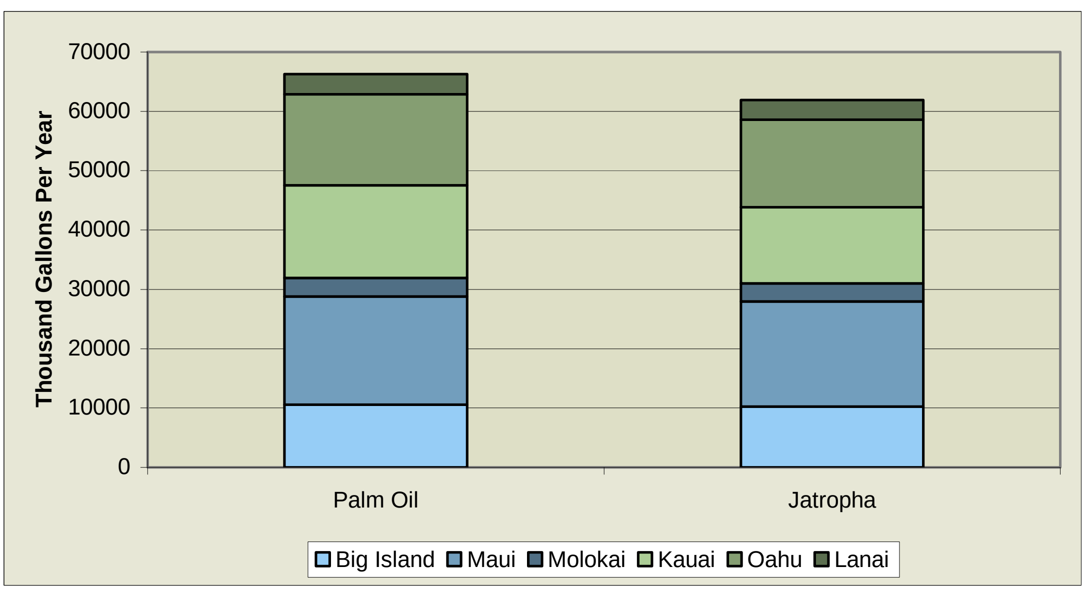

Figure 5-32. Biomass Potential by Crop Type and Island, Biodiesel.

5.2.3 Summary and Recommendations

The analysis projects that Hawai'i could produce 757 million gallons per year of ethanol from Eucalyptus and Banagrass planted in prime, irrigated farmlands in Hawai'i. Figure 5-33 shows the breakdown of potential by island, assuming a yield of 80 gallons per ton of biomass.

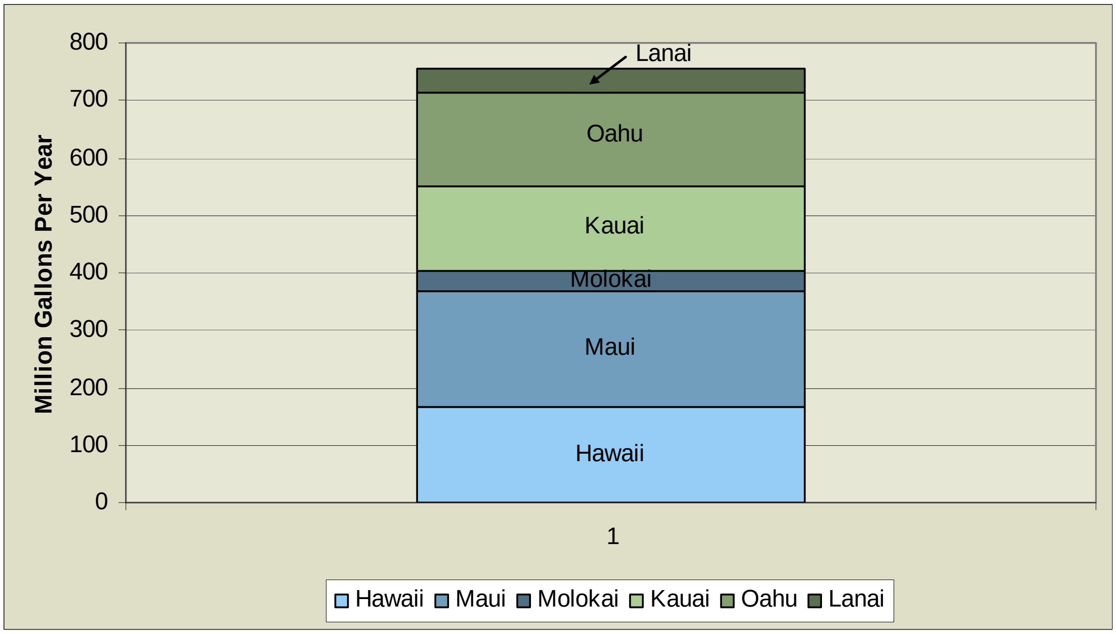

Figure 5-33. Irrigated Crop Ethanol Potential, By Island.

This ethanol yield is roughly 70 percent higher than the potential of non-irrigated land and is distributed much more evenly from a geographic perspective. More than 70 percent of the non-irrigated potential was on the Big Island, while there is much more potential near more heavily concentrated population centers if irrigated, prime farmland is used.

The following are recommendations for consideration or further work:

- The importance of varieties. The current analysis is based on varieties that were used in experiments and trials. Improved varieties are constantly being produced. For example, a company in Costa Rica has developed hybrid Oil Palm that is reported to yield 700 to 800 gallons of oil per acre per year. That is double the yield that was used in this analysis. It is yet to be shown that these high yields can be obtained consistently outside of Costa Rica or in Hawai'i. Similarly, there are reports that new high-yielding Jatropha varieties are near production. It is yet to be seen whether these lines are released and yielding as well as reported.

- The yields reported are broad given a range of literature estimates. More work is needed to confirm these yield estimates.
- The yields reported are mostly based on experimental plots. Yields on research stations are almost always higher than production fields.
- The yields are assumed to be for fully irrigated fields. No attempt has been made to estimate whether there is adequate water resources to fulfill the crop requirements.

6.0 Evaluation of Energy Crop Economics in Hawai'i

The objectives of this section are to address the economic feasibility of selected bioenergy crops for Hawai'i and compare their cost competitiveness in terms of cost per Btu of feedstock produced. The selected feedstock consists of both ethanol and biodiesel producing crops. Ethanol feedstock includes sugar feedstock (sugarcane) and cellulosic feedstock (Banagrass, Eucalyptus, and Leucaena). Biodiesel feedstock consists of Jatropha and Oil Palm.

For the economic analysis a net economic returns model was used to select economically feasible feedstock for biofuel production. For each feedstock, net return, feedstock cost per Btu, and feedstock cost per gallon of ethanol/biodiesel, the breakeven price of feedstock and the breakeven price of ethanol/biodiesel were calculated.

It should be noted that the costs to convert cellulosic feedstock to ethanol are still preliminary, and results should be interpreted with caution. Although it appears that Banagrass is the leading biofuel crop candidate among the six selected crops, the process of converting cellulosic feedstock into ethanol is still in the demonstration phase, and results should be treated as preliminary.

6.1 Data

The majority of the investigated crops are not widely grown in Hawai'i; hence, finding appropriate field data for economic analysis is challenging. For Banagrass, sugarcane, Eucalyptus, and Leucaena, data from previous studies were used. Production of Jatropha was assumed as analog to macadamia nut. For analysis of crops such as Oil Palm, data from foreign studies were used. Table 6-1 gives the basis for the data sources.

Table 6-1. Bioenergy Crop Data Source Locations.

Hawai'i Sources	Production Similar to Other Crops (Analog)	Analogous Climate
Banagrass	Jatropha	Oil Palm
Sugarcane		
Eucalyptus		
Leucaena		

6.2 Framework for Economic Analysis

A net economic returns model was used to evaluate and compare the economically feasibility of biofuel production for different energy crop options. The cost of producing each feedstock was evaluated using common cost categories including land preparation, planting, fertilization, weed control, and harvesting. Although the analysis concentrates on the production of feedstock, energy conversion assumptions are also utilized so that preliminary analysis involving the processing of feedstock to biofuels can be conducted. Since some of the conversion technology is still in the development phase, the estimated costs should be considered very preliminary and could potentially vary widely.

It should be noted that certain field operations are not performed regularly and uniformly year after year; therefore, annual costs may differ over the crop's life. From an economic point of view, the overall approach was to estimate average annual costs and returns over the entire economic life of the crop, which allowed for direct comparison among different crops. To calculate costs and revenues in annual equivalent terms, the present values of all costs and revenues over the useful life of the crop was transformed into an equivalent annuity. The following procedure was used in estimating annual equivalent cost and revenue (Monti et al., 2007)

1. Present value of the total investment over a 25 year period was estimated as follows:

$$PV = \sum_{t=0}^{n} FV_n \times (1+i)^{-n}$$

2. Annual Equivalent Cost (AEC) and Annual Equivalent Revenue (AER) were estimated as follows:

$$AEC = \frac{PV_c \times i}{1-(1+i)^{-n}} \qquad AER = \frac{PV_R \times i}{1-(1+i)^{-n}}$$

In this analysis, n was assumed equal to 25 years and i was 4.5 percent (the average historical discount rate during 1986 to 2006 from the Federal Reserve System). PV_C and PV_R are the present value of cost and revenue, respectively, over the 25 year period. The analysis for each crop was based on assumptions, modifications, and adjustments that are explained in the technical notes for each crop (Appendix A).

Feedstock cost of ethanol per 1,000 Btu was estimated by dividing the cost per acre of producing each feedstock by the corresponding crop's total per acre energy production. Total energy per gallon of ethanol and biodiesel are 76,300 Btu and 118,000 Btu, respectively (Jaeger et al., 2007). Feedstock cost of either a gallon of ethanol or biodiesel was estimated by dividing the per acre cost of producing the feedstock by the total gallons (per acre) of ethanol/biodiesel produced for each crop.

The breakeven price of feedstock is the price of feedstock at which the net revenue equals zero. The breakeven price of ethanol or biodiesel is the price of energy at which the net returns in terms of energy equal zero. The breakeven price is calculated as cost divided by yield, where yield is either in terms of feedstock or the appropriate conversion to energy.

6.3 Results

6.3.1 Base Case, Rainfed Cases

Table 6-2 and Table 6-3 provide a comparison of crop yields, ethanol/biodiesel yields, feedstock costs per gallon, and feedstock costs per 1,000 Btu for the selected crops, based on rainfed and irrigated land. Banagrass has the highest ethanol production (1,440.5 gallons/acre/year) and Oil Palm has the highest biodiesel production (203.4 gallons/acre/year). Feedstocks used for producing ethanol have lower feedstock costs (per gallon and per 1,000 Btu) than feedstocks used for the production of biodiesel.

Table 6-2 and Table 6-3 summarize the major components of the economic analysis, including analysis involving the feedstock and conversion of the feedstock to either ethanol or biodiesel. The major findings are as follows:

- Net returns (based on feedstock price) are not available for Eucalyptus and Leucaena because of the absence of feedstock price data. Of the remaining bioenergy crops investigated, only Banagrass shows a positive net return per acre.
- High production costs are primarily due to field operation costs (fertilizer, pesticides, and other chemical application) and harvesting costs. With improved yields, the cost component can be reduced and net returns improved.
- Net returns after conversion to ethanol and biodiesel show irrigated Banagrass production on prime land as having highest positive net returns from ethanol production. This is due to the crop's high energy yield (conversion to ethanol). However, it should be noted that costs to convert cellulosic feedstock to ethanol are still under investigation and, therefore, the results should be interpreted with caution.
- Compared to ethanol, feedstock costs per gallon of biodiesel crops are higher. Jatropha and Oil Palm research in Hawai'i is still in its infancy and yield

improvements, development of harvesting machinery, and improved production practices could substantially reduce costs and improve net returns for these oil producing crops.

- Break-even prices for ethanol producing crops (sugarcane, Banagrass, Eucalyptus, and Leucaena) are lower than biodiesel producing crops (Jatropha and Oil Palm).

With the assumptions used in the base case evaluation, the net returns analysis showed that Banagrass grown on irrigated prime land had the highest positive net return (i.e., when the price of Banagrass is measured as a feedstock or in terms of ethanol).

Table 6-2. Biofuel Yields and Feedstock Cost, Rainfed Land

Crop	Yield (acre/yr)	Conversion Factor	Ethanol (Biodiesel) (gallons/acre/ year)	Feedstock Cost (per 1000 BTU)	Feedstock Cost (per gal)
Ethanol					
1. Sugarcane					
Sugar fermentation	23.8 wet tons*	19.5 gal/wet tons cane*	464	$0.018	$1.25
Residue (cellulosic)	4 dry tons	80 gal/dry tons residue	324		
Sugarcane total			788		
2. Banagrass	21.5 dry tons	80 gal/dry ton	1,720	$0.010	$0.74
3. Eucalyptus	7.8 dry tons	80 gal/dry ton	624	$0.018	$1.31
4. Leucaena	8.8 dry tons	80 gal/dry ton	704	$0.010	$0.70
Biodiesel					
5. Oil Palm	226 gal	0.9 gal biodiesel/gal oil	203	$0.090	$10.60
6. Jatropha	114 gal	0.9 gal biodiesel/gal oil	103	$0.154	$18.16

Notes:

* Moisture content for sugarcane can be approximated as 70 percent.

Table 6-3. Biofuel Yields and Feedstock Cost, Irrigated Land

Crop	Yield (acre/yr)	Conversion Factor	Ethanol (Biodiesel) (gallons/acre/ year)	Feedstock Cost (per 1000 BTU)	Feedstock Cost (per gal)
Ethanol					
1. Sugarcane					
Sugar fermentation	52 wet tons*	19.5 gal/wet tons cane*	1014	$0.03	$0.90
Residue (cellulosic)	8.8 dry tons	80 gal/dry ton residue	704		
Sugarcane total			1718		
2. Banagrass	37 dry tons	80 gal/dry ton	2960	$0.009	$0.58
3. Eucalyptus	9 dry tons	80 gal/dry ton	720	$0.020	$1.22
4. Leucaena	12 dry tons	80 gal/dry ton	960	$0.013	$0.59
Biodiesel					
5. Oil Palm	300 gal	0.9 gal biodiesel/gal oil	270	$0.068	$7.98
6. Jatropha	290 gal	0.9 gal biodiesel/gal oil	261	$0.06	$7.14

Notes:

* Moisture content for sugarcane can be approximated as 70 percent.

Table 6-4. Economic Summary of Sugar and Cellulosic Feedstocks, Rainfed

Cost Items	Unit	Sugarcane	Banagrass	Eucalyptus	Leucaena
1. Land Preparation	$/acre/year	$292.84	$34.94	$8.21	$8.24
2. Planting	$/acre/year	$28.94		$4.22	$4.24
Seeds/plants	$/acre/year		$1.66		
3. Field Operations					
Fertilizer	$/acre/year	$65.98	$187.98	$62.46	$42.20
Herbicides	$/acre/year	$171.89	$140.51	$109.82	$48.60
Other	$/acre/year			$35.67	
4. Harvesting	$/acre/year	$290.07	$277.23	$490.54	$236.33
Other	$/acre/year		$224.06	$3.82	$40.92
5. Other Operations	$/acre/year		$282.92	$6.40	$54.99
6. Operating Overhead	$/acre/year	$84.97	$114.93	$72.11	$38.05
Total Costs	$/acre/year	$934.69	$1,264.24	$793.26	$473.56
Fixed Cost	$/acre/year	$93.47	$56.08	$79.33	$47.36
Total Variable Cost	$/acre/year	$841.22	$1,208.16	$713.94	$426.21
A. Feedstock Production					
Primary Production	Tons	47.60 (wet)	21.50 (dry)	7.80 (dry)	8.80 (dry)
Gross Revenue	$/acre/year	$815.08	$1,802.99		
Net Revenue (per acre)	acre/year	-$119.61	$538.75		
B. Production of Ethanol					
Total Processing Cost	$/acre/year	$439.52	$2,339.20	$848.64	$957.44
Total Production Cost	$/acre/year	$1,890.02	$3,603.44	$1,641.90	$1,431.00
Gross Revenue (ethanol)	$/acre/year	$1,892.07	$4,137.50	$1,501.05	$1,693.49
Net Revenue (ethanol)	$/acre/year	$2.06	$534.06	-$140.86	$262.49
Feedstock Cost of Ethanol	$/1,000 Btu	$0.018	$0.010	$0.018	$0.010
Feedstock Cost of Ethanol	$/gallon	$1.21	$0.74	$1.27	$0.67
Breakeven Price of Feedstock	$/ton	$41.95	$58.80		
Breakeven Price of Ethanol	$/gallon	$2.40	$2.10	$2.63	$2.03

A summary of the breakdown between production and harvesting costs for each feedstock can be seen in Figure 6-1. For the base case assumptions used in this analysis it appears that Banagrass and Leucaena could have an economic advantage compared to sugarcane and Leucaena. Given the challenges associated with estimating future projected energy crop yields, conversion efficiencies, and conversion costs for the these emerging biofuel applications, the difference in the projected breakeven costs for these four crops is not dramatic. As these options are commercialized, actual project and production costs could swing up or down from those illustrated here, leaving room to justify the continued exploration of all these energy crop alternatives.

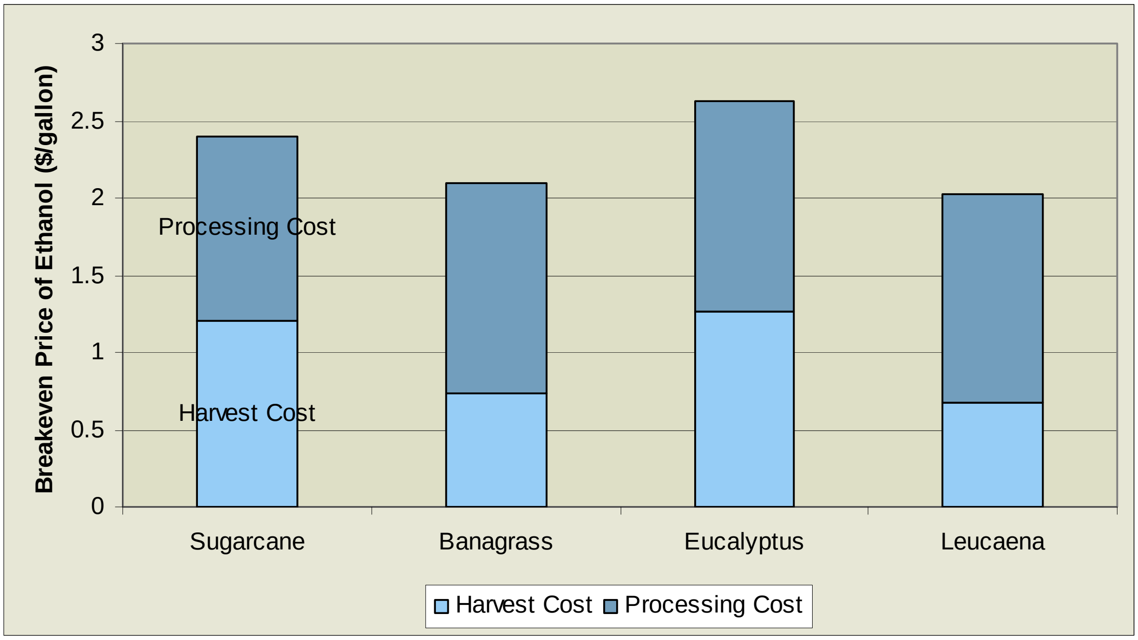

Figure 6-1. Breakeven Ethanol Cost Components, Rainfed Feedstocks.

A summary of the cost components and the breakeven cost for biodiesel can be seen in Table 6-5 below. Note that processing cost is only a very small proportion of the breakeven sales value.

Table 6-5. Economic Summary of Feedstock and Biodiesel Data

Cost Items	Unit	Oil Palm	Jatropha Scenario 1*	Jatropha Scenario 2**
1. Land Preparation	$/acre/year	$8.21	$8.21	$8.21
2. Planting	$/acre/year		$4.22	$4.22
Other	$/acre/year	$134.92		
3. Field Operations				
Machinery	$/acre/year		$130.29	$130.29
Labor	$/acre/year	$28.94	$212.28	$212.28
Fertilizer	$/acre/year	$359.11	$131.70	$131.70
Herbicides	$/acre/year	$114.06	$52.51	$52.51
4. Harvesting	$/acre/year		$874.65	$874.65
Machinery	$/acre/year	$23.06		
Labor	$/acre/year	$307.83		
Other	$/acre/year	$352.07		
5. Other Operations	$/acre/year	$467.37	$141.52	$141.52
6. Operating Overhead	$/acre/year	$179.98	$155.54	$155.54
Total Variable Costs	$/acre/year	$1,979.76	$1,710.93	$1,710.93
Fixed Cost	$/acre/year	$175.90	$152.01	$152.01
Total Cost	$/acre/year	$2,155.66	$1,862.93	$1,862.93
A. Feedstock Production				
Primary Production	Gallons	226.00	114.00	114.00
Gross Revenue	$/acre/year	$447.25	$233.10	$396.30
Net Revenue (per acre)	acre/year	-$1,708.41	-$1,629.84	-$1,466.64
B. Production of Biodiesel				
Total Processing Cost	$/acre/year	$133.34	$59.08	$59.08
Total Production Cost	$/acre/year	$2,289.00	$1,922.02	$1,922.02
Gross Revenue	$/acre/year	$454.62	$201.45	$342.49
Net Revenue from Biodiesel	$/acre/year	-$1,834.38	-$1,720.57	-$1,579.53
Feedstock Cost of Biodiesel	$/1,000 Btu	$0.090	$0.154	$0.154
Feedstock Cost of Biodiesel	$/gallon	$10.60	$18.16	$18.16
Breakeven Price of Feedstock	$/ton	$9.54	$16.34	$16.34
Breakeven Price of Biodiesel	$/gallon	$11.25	$18.73	$18.73

*Scenario 1: Palm oil price as a substitute for Jatropha oil price.
**Scenario 2: Soybean oil price as a substitute for Jatropha oil price.

6.3.2 Sensitivities

The analysis explored the sensitivity of the economic model to variations in the major inputs for the Banagrass case. The major items investigated are listed below:

- Total Harvest Costs
- Yield of biomass (tons per acre per year)
- Processing cost
- Yield of ethanol per ton

In the sensitivity analysis, each individual input was varied from the base case while all other inputs were held constant. The effect on the breakeven ethanol sales price was recorded and plotted against the corresponding input value. The results of the analysis for each of these variables can be seen on Figure 6-2. While this analysis was done specifically for the Banagrass case, the impacts of the variables are likely to be similar for other feedstocks.

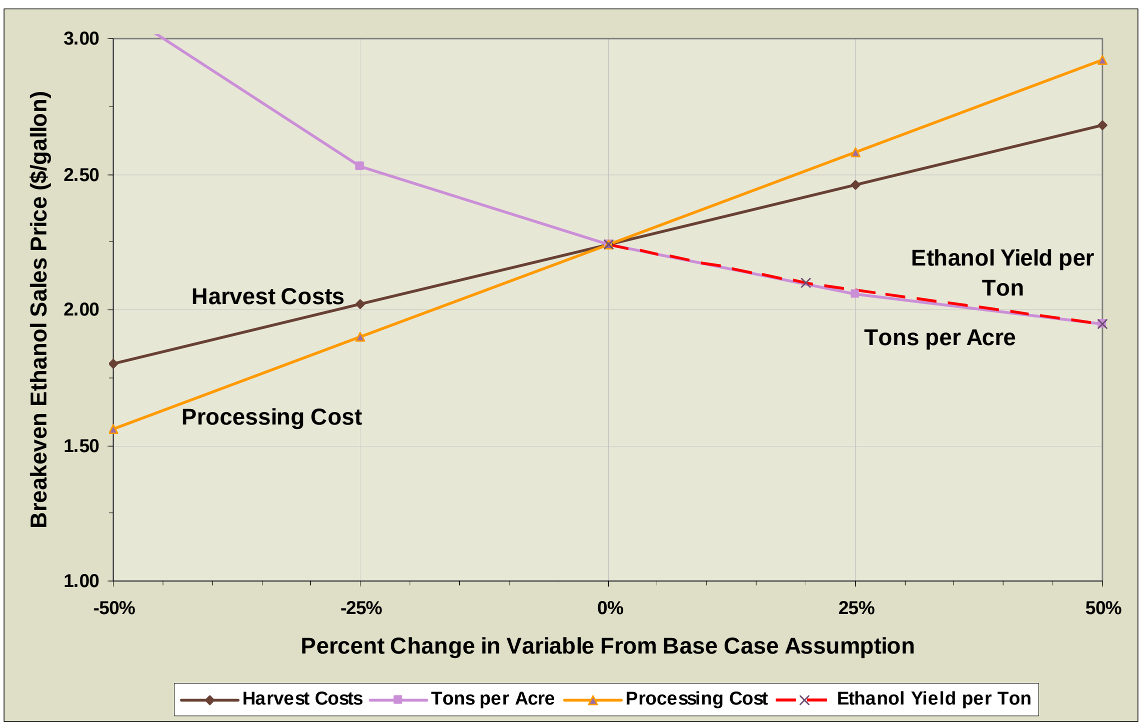

Figure 6-2. Banagrass Financial Model Sensitivities.

The lines on Figure 6-2 with the steepest slopes generally represent the inputs with the greatest impact on the financial return. The two most significant inputs that could improve the economics are the Harvest and Processing Costs. For an equivalent change in input, these factors have a greater impact on the breakeven price of ethanol relative to the yields of biomass per acre or the yield of ethanol per ton of biomass. The tons of biomass per acre and gallons of ethanol per ton of biomass have almost identical impacts on the economics if they were to improve; a 25 percent improvement in each would reduce the breakeven ethanol sales price to just over $2 per gallon. This analysis shows that improving processing cost, which is very uncertain at this time due to the nascent technology available for cellulosic ethanol conversion, should be the area of greatest focus to help improve the overall system economics.

One area commonly sited as being a major potential improvement in cellulosic ethanol technology is increasing the yield of ethanol per ton of feedstock. The base case assumed 80 gallons per ton of feedstock, which represents the anticipated state of technology in the next four to five years. The impact on the breakeven price of cellulosic ethanol ranging from a conservative conversion estimate of 67 gallons per ton to an expected future potential of 100 gallons per ton for each of the four feedstocks can be seen in Figure 6-3.

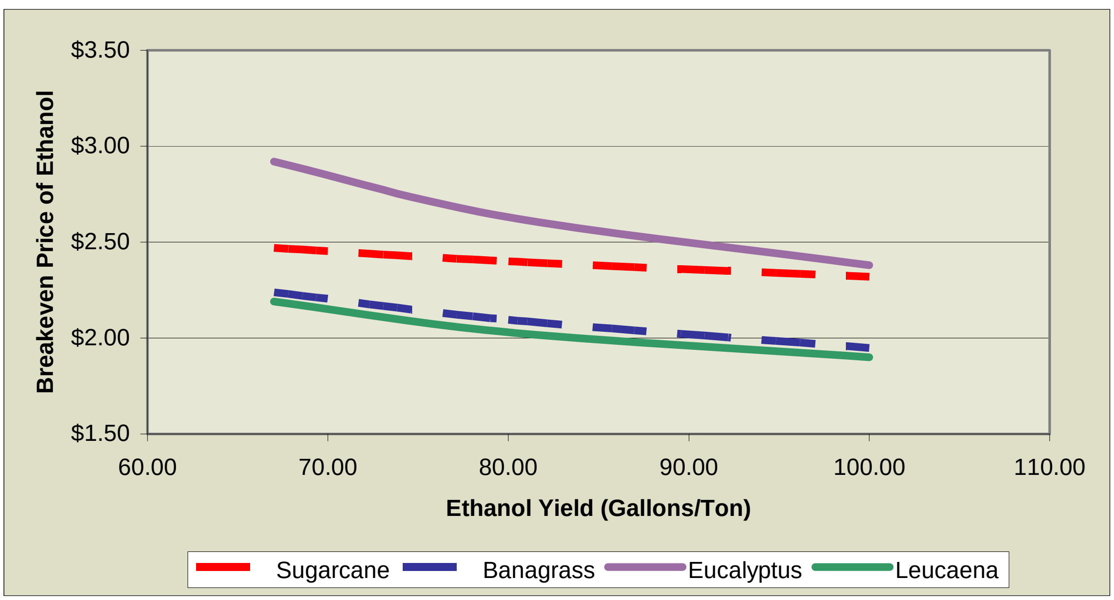

Figure 6-3. Ethanol Yield Sensitivity Analysis.

Major improvements in conversion technologies may be able to raise the yield of ethanol per ton to the 100 gallon range. While these sorts of improvements would be helpful to lower the cost of production, the benefit is relatively modest (lowering production costs by roughly $0.25/gallon for most feedstocks) given the major technical improvement that this entails. Woody feedstocks are impacted more strongly due to their lower ton yield per acre. The sensitivity in processing costs for Eucalyptus and Leucaena is illustrated in Figure 6-4, where a lower processing cost of $1.36/gallon is compared to a higher processing cost of $1.62/gallon, with a resulting difference of roughly 10 percent in the breakeven costs of ethanol production.

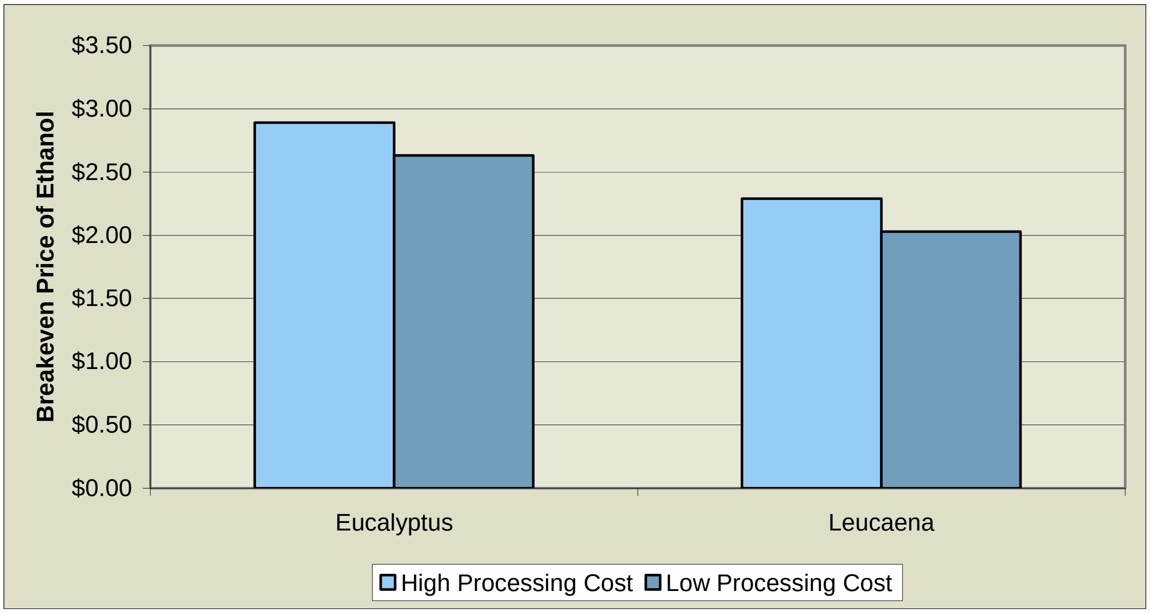

Figure 6-4. Woody Feedstock Processing Cost Sensitivity Analysis.

6.3.3 Base Case, Irrigated Cases

The results presented above specifically highlight the costs for ethanol production from rainfed crops. The economic analysis also explored the production cost of ethanol from irrigated Banagrass and sugarcane. While the costs for irrigation negatively impact the economics of production, the higher yield from irrigation typically makes irrigation cost effective. The results of this analysis can be seen in Table 6-6 below.

Table 6-6. Economic Summary of Sugar and Cellulosic Feedstocks, Irrigated			
Cost Items	**Unit**	**Sugarcane**	**Banagrass**
1. Land Preparation	$/acre/year	$292.84	$34.94
2. Planting	$/acre/year	$28.94	$1.66
3. Field Operations			
Non-Irrigation Costs	$/acre/year	237.86	328.50
Irrigation	$/acre/year	601.61	410.15
4. Harvesting	$/acre/year	$290.07	$277.23
5. Other Operations	$/acre/year	$0	$282.92
6. Operating Overhead	$/acre/year	$145.13	$155.95
Total Costs	$/acre/year	$1,596.46	$1,715.40
Fixed Cost	$/acre/year	$159.65	$76.09
Total Variable Cost	$/acre/year	$1,436.81	$1,639.31
A. Feedstock Production			
Primary Production	Tons/year	52 (wet)	37 (dry)
Gross Revenue	$/acre/year	$1,780.84	$3,102.83
Net Revenue (per acre)	$/acre/year	$184.38	$1,387.42
B. Production of Ethanol			
Total Processing Cost	$/acre/year	$480.15	$4,025.60
Total Production Cost	$/acre/year	$2,320.12	$5,741.00
Gross Revenue (ethanol)	$/acre/year	$2,916.24	$7,120.35
Net Revenue (ethanol)	$/acre/year	$474.45	$1,379.35
Feedstock Cost of Ethanol	$/1,000 Btu	$0.029	$0.008
Feedstock Cost of Ethanol	$/gallon	$0.94	$0.58
Breakeven Price of Feedstock	$/ton	$65.30	$46.36
Breakeven Price of Ethanol	$/gallon	$2.13	$1.94

The economics of both the sugarcane and Banagrass cases under irrigation show unambiguous improvements relative to the rainfed economics. The net revenue for sugarcane however remains lower than for Banagrass, making it likely that Banagrass could be a more attractive route for maximizing the production of cellulosic ethanol in Hawai'i of the projected high yields of Banagrass can be achieved.

A comparison of the production and harvesting costs for sugarcane and Banagrass can be seen in Figure 6-5. In both cases, the breakeven price of ethanol is lower in the irrigated case when compared to the rainfed cost. This is due to the lower harvest cost from the greater yield of feedstock per acre.

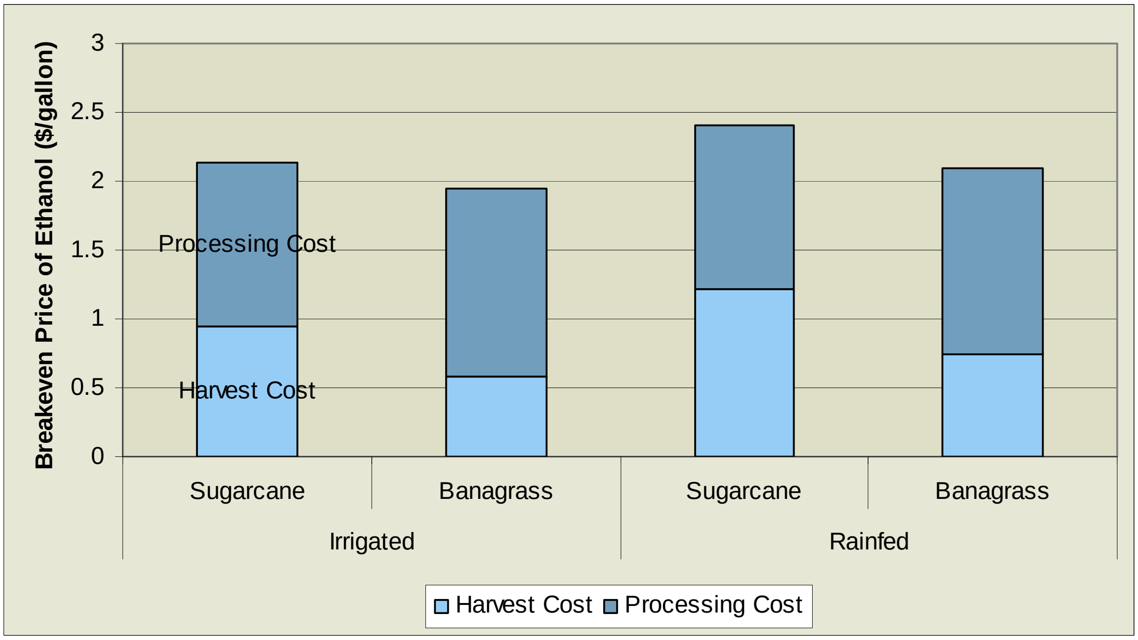

Figure 6-5. Breakeven Ethanol Cost Components, Rainfed versus Irrigated.

6.4 Summary

Of all the biofuel crop options evaluated, irrigated Banagrass grown on prime land showed the most promising net returns, primarily because of the high crop yields per acre anticipated with this crop.

Compared to ethanol, feedstock costs per gallon (or per 1,000 Btu) of biodiesel are considerably higher. Jatropha and Oil Palm research in Hawai'i is in its initial stage and yield improvements and development of harvesting machinery are needed before net returns for these biodiesel producing crop are economically viable in Hawai'i.

7.0 Emerging and Innovative Options for Biofuel Production

There are a number of emerging strategies and crop alternatives that offer promise for biofuels production in Hawai'i. These include alternatives such as:

- Selection and development of new crop species.
- Microalgae production.
- Research to improve existing crop yields.
- Integrated "biorefinery" approaches that produce high value chemicals and fuels.
- Strategies to produce food/feed and fuel from common acreage.
- Multidimensional ecotourism or agritourism approaches linked to sustainable bioenergy farms and processing facilities.

These options are in various stages of development, requiring further research to determine their full potential and viability. Highlights of these alternatives are summarized below.

7.1 New Crop Alternatives

In addition to the crops evaluated in detail in this study, there are other crops which have the potential to play a role in Hawaii's bioenergy future. The most notable of these alternative crops are sweet sorghum and algae.

Sorghum is already grown commercially to produce food, fiber, and animal feed around the world. There are several varieties of sorghum but many strains are well suited to hot and arid regions that are not suitable for other forms of agriculture. In addition, sorghum can produce high biomass yields, and up to three harvests per year may be achievable in Hawaii's climate.

Sweet sorghum is seen by organizations such as Hawaii BioEnergy LLC as having very strong potential as an energy crop in Hawai'i. Since the plant readily produces seeds for propagation, efforts to improve yields through plant selection techniques should be able to progress rapidly. Similar to sugarcane, conventional conversion options (or conventional, combined with advanced conversion options), could be used to convert the sugar and as well as the fiber from sweet sorghum into co-products of biofuel and electricity.

7.2 Microalgae

Microalgae is one alternative crop that has been identified for its interesting characteristics and biofuel production potential. With funding from the U.S. Department of Energy (DOE), the National Renewable Energy Laboratory (NREL) engaged in algae to biofuel research from the late 1970's through the mid 1990's. In recent years with the volatility of petroleum based fuels and increasing concerns about climate change, this work has been revisited and has gained interest from numerous organizations, including major petroleum companies such as Chevron and Shell.

7.2.1 The Potential for Microalgae

There are a number of characteristics that make algae attractive as a potential feedstock for the production of biofuels. One of the major advantages of algae is that it does not compete directly for land and resources that could otherwise be used to grow crops for food. Algae can survive in water with high salt content and use water that would otherwise be deemed unusable. With recent controversies regarding the use of agricultural land to produce crops for biofuels, these traits offer a significant advantage over traditional oil seed crops for biofuels production.

High projected yields per acre are another reason that algae has been identified as an attractive feedstock for biofuels production. Fast growth rates and high oil content mean that algae can potentially produce 10 times or more lipids (oils) per acre than soybeans or other oil seed crops. With continued development, it may be possible to produce algae that has up to 70 percent of its mass in the form of usable oils, and this combined with the fast growth rates lead to a high biological efficiency. Current projections estimate that 6,000 to 15,000 gallons of biofuel per acre of algae may be achievable.

7.2.2 Algae to Biofuels Technology Development

A primary challenge facing biofuels production from algae is economic. Research is underway to identify the most appropriate strains. Work also continues on refining methods for extracting and processing the oils. Although the process of making biofuels from algae is already known and proven, there are obstacles that need to be overcome before the process can be implemented on a commercial scale

Algae is already grown commercially in some parts of the world; primarily for the production of food, dyes and pharmaceuticals. Open systems such as raceway-type ponds have commonly been used in the cultivation of algae for these types of operations. However, open systems can be susceptible to contamination by invasive strains of algae or other microorganisms. This tends to limit the types of algae that can be effectively cultivated in open ponds and raceways. For this reason, closed systems such as photobioreactors (PBR) have been investigated for the production of algae for biofuels. PBRs are transparent vessels which allow light in and essentially act like a greenhouse preventing contamination and water losses due to evaporation. However, capital cost for these closed systems are much higher comparatively than open systems and at this time it appears unlikely that these systems will be economical in the near term. It may be more likely that advances in breeding and genetics will lead to more robust strains where closed systems are not needed.

It is clear that before algae-to-biofuel production sees widespread commercialization there is significant research and development that still needs to be done. Some of the main areas of current investigation include:

- Faster growth, higher biological efficiency.
- Resistance to biological attack.
- Wider ambient growing conditions.
- Higher percent of total biomass as oil.
- Reduced water and nutrient requirements.

In addition, there are some novel approaches to algae cultivation still being investigated and developed. One concept that has gained attention is the idea of using algae to sequester carbon dioxide emissions. Since carbon dioxide is required for algae to grow, the opportunity exists to use algae to capture carbon dioxide emitted from the stack of a fossil fuel fired power plant.

7.2.3 Microalgae in Hawai'i

Hawai'i appears to be well positioned to emerge as a leader in the research, development and production of biofuels from algae. The state's climate is ideal for algae aquaculture and the state's dependence on imported liquid transportation fuels makes it a promising place for marketing and developing new biofuels technologies. Several organizations including large multinational energy companies have been involved with the development of demonstration projects in Hawai'i.

HR BioPetroleum has partnered with a variety of companies including Royal Dutch Shell and subsidiaries of Hawai'ian Electric Industries to develop technologies for the commercial scale cultivation of algae for biofuels. One of the primary goals for HR BioPetroleum is to identify strains ideal for oil production. In 2007, HR BioPetroleum partnered with Royal Dutch Shell on a two-year demonstration project to grow 6 acres of algae. In addition, HR BioPetroleum has intentions of developing a large scale production facility on Maui. In July of 2009, HR BioPetroleum announced plans that it would work with Alexander & Baldwin, Inc., Hawai'ian Electric Company and Maui Electric Company to develop a commercial scale algae production facility. Alexander & Baldwin, Inc. will provide land next to Maui Electric's Ma'alaea Power Plant so that stack gasses produced at the plant can be used to supply carbon dioxide to the algae. At the time the announcement was made, predictions stated that the facility could be operational as early as 2011.

Khuehnle AgroSystems is another Hawai'ian company involved in algae research. The company has worked alongside HR BioPetroleum using natural and genetic modification techniques to create customized strands specifically for biofuels production.

Two other companies Imperium Renewables Hawai'i and Kai BioEnergy Corp have also announced plans for algae to biodiesel facilities in Hawai'i. Imperium Renewables Hawai'i has announced plans to develop and build a $90 million biodiesel plant in Kawolei. The facility will be adjacent to new a HECO power plant that will use the fuel produced at the new biodiesel facility. Kai BioEnergy has announced plans to develop a biodiesel from microalgae process on the Big Island.

Land availability for thousands of acres of algae ponds in Hawai'i would clearly present some unique challenges in comparison to conventional crop production. As noted above, commercially algae production strategies are expected use raceway ponds for cultivation, which require level horizontal surfaces; this could be a challenge in Hawai'i since much of the terrain is slopped.

7.3 Improvement of Existing Crops

The science of agriculture is continually advancing. As crops selected for biofuel production are grown in greater quantities, it is likely that progress will be made in the science of these crops as well. Methods of crop production are also likely to improve over time. Selected breeding and genetic modification techniques give agriculturalists great control over trait selection and expression. Over time this may produce greater yields or enhance the quantity or characteristics of the most desirable parts of the crop.

Even with established crops there may be a benefit to changing production strategies as technology and markets for biofuels develop. One example of this is energy cane, which is a variation of sugar cane that would produce greater overall cellulosic biomass yields than plant varieties used for conventional sugar production. The increased fiber yields would be attractive for bioenergy applications, either as feedstock that could be converted to liquid fuel in advanced conversion systems, or as feedstock that could be use for electric power production (using conventional boiler technology, pyrolysis, or gasification). Energy cane would also produce significant amounts of easily fermentable sugars that could be recovered for ethanol production.

7.4 Biorefineries

The primary goal of refining is to add value to raw feedstock materials by reorganizing elements into useful products. Traditional petrochemical refining utilizes the mixture of carbohydrates found in crude oil and performs a variety of cracking and separation processes to produce multiple streams of fuels and commodity chemicals. The petrochemical refining model has evolved over the last century and markets for fuels and commodities chemicals (such as those used to produce plastics) have evolved with the refining process.

With biorefining the goals are the same, however since the structure and properties of biomass differ significantly from that of fossil fuels, the processes and end products will also vary. Traditional petrochemical refining relies primarily on thermochemical processes. Biorefineries could use either biological processes such as fermentation and enzymatic hydrolysis, or thermal processes such as gasification or pyrolysis to breakdown biomass feedstocks and reassemble the constituents into various products. Since there are a wide variety of biomass feedstocks and conversion processes options, the type of products that could be produced at biorefineries is quite varied. While the products of petrochemical refining are generally limited to fuels, energy and chemicals, biorefineries are could produce food, animal feed or fertilizers in addition to these products.

There are a number of visions of biorefining of different potential feedstocks, but all produce a variety of different products and have the goal of maximizing the value commodities produced and minimizing wastes. Hawai'ian company HR BioPetroleum presents one vision of biorefining for algae feedstocks. Figure 7-1 below shows the possible inputs and outputs for an algae based biorefinery operation.

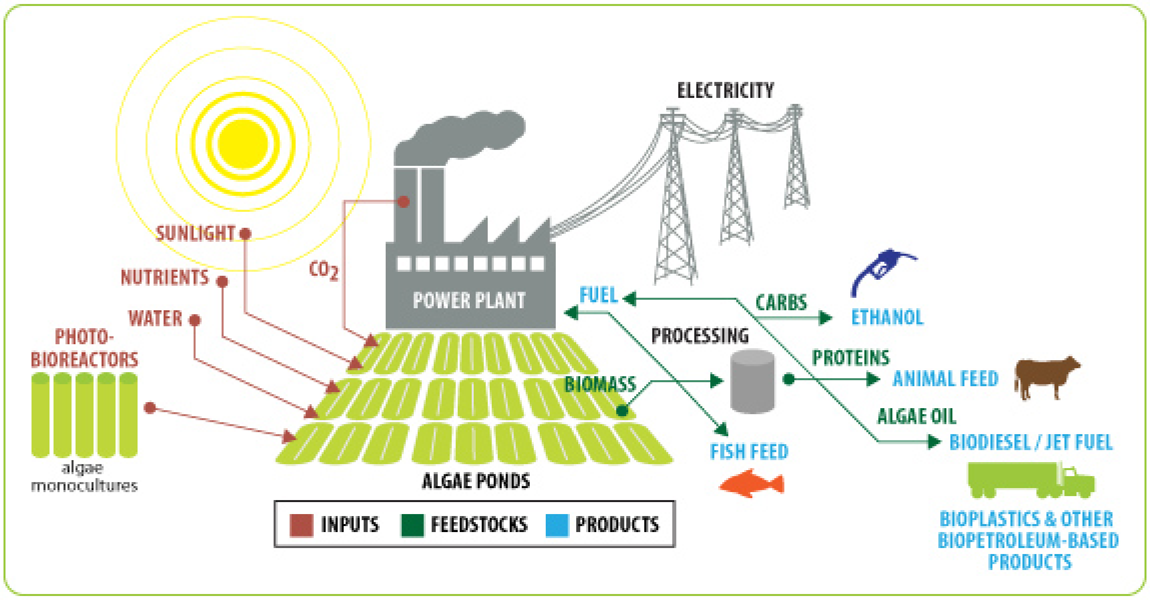

Figure 7-1. Input and Output Streams for a Conceptualized Algae Fed Biorefinery (Source HR BioPetroleum).

Though the potential for biorefining is great, there are still numerous challenges that must be worked through. The primary challenge is making fuel and other products from biomass economically. To many consumers this translates into an expectation that fuels and chemicals produced from biomass will have comparable pricing to their petroleum-based predecessors.

A variety of factors can tend to put upward pressure on biomass feedstock costs in comparison to fossil fuel costs. Biomass is more geographically dispersed, lower in energy density, and there can be seasonal variations in the availability that are not found with fossil fuels. In addition, the properties of biomass can vary significantly by type and region, thus making it possible that different processes will need to be developed for specific biomass feedstocks.

All these potential obstacles to developing a biobased economy reinforce the need to seek high material utilization and to create high value products to the extent possible. Both of these are goals for biorefining models. Just as petrochemical refining evolved over the course of the 20th century, a similar evolution could occur in biorefining over the course of the 21st century. While biorefining is in many ways still in its infancy, models for biorefining are starting to take shape. Large agricultural processing plants, such as those used to mill corn, process soybeans or produce ethanol, are adding secondary processes to utilize fractions of the plant that were previously considered waste materials. For example, some large ethanol plants have added anaerobic digestion or gasification processes to recover energy from distiller's grain, where the demand for this co-product saturates animal feed markets.

The development of integrated biorefineries is seen as fundamental to building a new bioeconomy. For this reason several government agencies have programs in place to help advance the science of biorefining. Much of this development has been organized through the US Department of Energy (DOE). The DOE's activities to support biorefining include:

- Provided funding to the National Renewable Energy Laboratory (NREL) and other public institutions to improve and develop new biochemical processes.
- Collaborated on a multi-year effort with Cargill Inc. and Codexis, Inc. on the development of technology to produce 3-hydroxypropionic acid (3-HP) from biomass. 3-HP is seen as having significant potential as a chemical intermediary for the production of a variety of commodity chemicals.
- Provided funding for demonstration scale cellulosic ethanol technology at an existing ethanol production facility. Operation of the cellulosic ethanol demonstration facility is expected to begin in 2011.

The U.S. Department of Agriculture has also been involved with supporting the development of biorefineries. The USDA Rural Development Program has established a Biorefinery Assistance Program that will guarantee loans for up to $250 million dollars for the development of integrated biorefinery facilities.

The Hawai'i – DOE Clean Energy Initiative could provide a framework for supporting and fostering research, development, and demonstration of biorefinery systems and applications in Hawaii.

7.5 Multi Crop Strategies Integrated Food and Fuel Production

The practice of rotating or sequencing dissimilar crops on the same plot of agricultural land has been used by farmers for centuries to prevent declines in soil fertility. With these long standing principles in mind, new models of integrated food and fuel production are beginning to emerge that have the potential to increase agricultural yields and better serve the needs of the environment in Hawai'i.

Alley cropping is one emerging strategy that has potential for integrated food and fuel production. With alley cropping, agricultural or horticultural crops are grown in-between rows of trees or shrubs. This method of farming offers a number of potential advantages over traditional industrialized agriculture where similar crops are planted over a large area. Figure 7-2 below shows an example of alley cropping. Figure 7-3 below is a diagram showing alley cropping with integrated animal grazing.

Figure 7-2. Alley Cropping of Herbaceous Plants with Trees (Source: USDA).

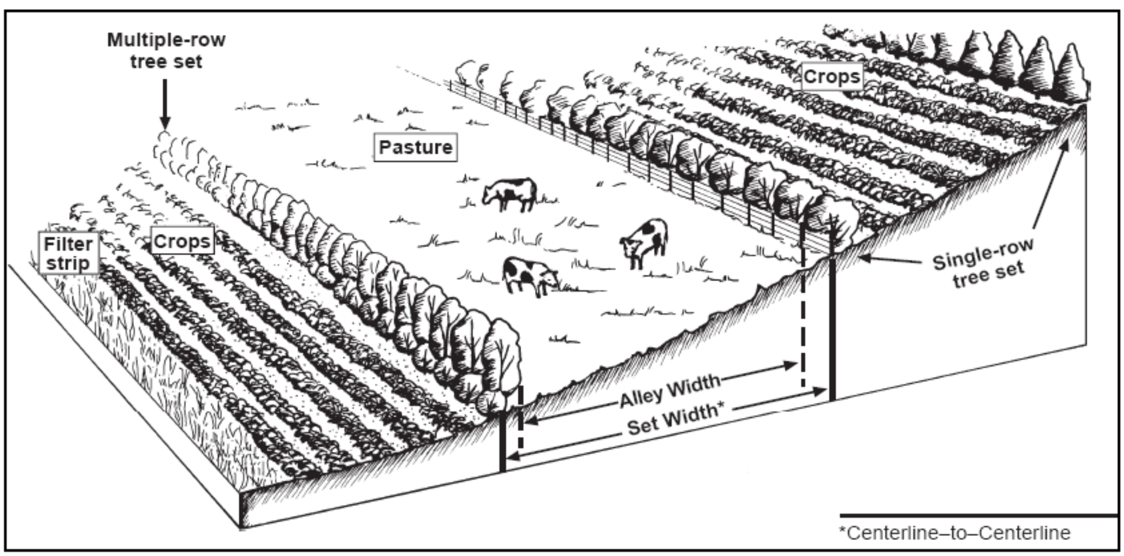

Figure 7-3. Alley Cropping with Integrated Grazing (Source: USDA).

Alley cropping has the potential to be a win-win situation, benefiting landowners and the environment alike. For landowners there is a potential to diversify income sources, which could make producers more resilient to market downturns or crop failure. Also, since different crops are harvested at different times of the year, revenue is generated more frequently. There are also opportunities to get greater utilization of idle growing areas. This is especially true in cases where tree crops will take years to mature. Idle areas in-between immature trees can be cultivated while other crops establish themselves. Landowners also benefit from enhance land quality that results from the environmental benefits of alley cropping.

Many of the potential environmental benefits of alley cropping are tied to incorporating greater biodiversity into a given region. Increased biodiversity can reduce the chances of pests or pathogens buildup that target a particular crop. A variety of plant species also means there is a greater diversity of nutrient mechanisms present in a given ecosystem. Different plants remove and contribute different mixtures of nutrients to the soil. This can lead to beneficial relationships between complimentary plants. In Hawai'i for example, Leucaena is known for its ability to fix atmospheric nitrogen into the soil. This ability is noteworthy especially since most plants deplete nitrogen from the soil. In addition to producing woody material as feedstock for energy uses, Leucaena is also a good forage crop for animals -- all animals favor Leucaena, one of the few woody tropical legumes that is highly digestible and relatively non-toxic. Other tropical leguminous trees that could be researched include kiawe, haole koa, monkeypod and koa.

Even when plants rely on the same nutrients, alley cropping does not necessarily lead to direct competition for nutrients or other resources such as water. Differences in root penetrations for different plants mean that resources can be pulled from different layers in the soil. This leads to greater water utilization and also helps with soil structure and prevention of erosion. Furthermore, deep rooted plants such as trees can pull nutrients from lower levels in the soil which end up in the foliage. As leaves fall to the ground, the nutrients return to the top of the soil and are accessible to plants with lesser root penetrations.

These opportunities for complimentary relationships between plants could lead to increased yields and higher income farming practices in Hawai'i, offering the potential for integrated food and fuel production from cropland. Large areas of land, such as pastureland in Hawai'i, provide very low economic returns per acre to land owners; multi-crop strategies for integrated fuel, fiber, food and/or forage production could offer win-win solutions for economic development and energy independence in Hawai'i.

7.6 Tourism

The incentives for conserving Hawaii's natural areas are of clear economic importance. While new models of fuel production and agriculture may arise to help advance Hawaii's energy independence, new models for tourism may develop alongside these industries. Innovation that may help Hawai'i move towards energy independence may also be a draw for people to the state and enhance the tourism experience.

7.6.1 Ecotourism

There is already a movement to promote more environmentally aware forms of travel. Ecotourism is one such type of travel that has been promoted in relatively undeveloped areas of Costa Rica, Ecuador, Nepal, Kenya and Madagascar. The ideas of ecotourism are based around the following principals:

- Minimize environmental impact.
- Increase environmental awareness.
- Provide direct benefits for conservation.
- Provide financial benefits and empowerment for local people.
- Respects local cultures.
- Supports human rights and demographic movements.

The ecotourism model demonstrates that there is demand for travel which is considered ecologically sensitive, which might be adaptable to Hawaii's well established tourism industry. Progress in Hawai'i toward developing a biofuels industry that is based on sustainable feedstock supply production and conversion may be adaptable to ecotourism principals and lead to enhanced tourism experiences and strengthening of tourism revenues in Hawai'i.

7.6.2 Agritourism

Developing a new biofuels industry in Hawai'i would bring changes to agriculture on the island. It is possible that these changes could encourage a new form of agritourism with a focus on sustainability. Innovation towards creating a biobased economy could make Hawai'i a destination for those interested in sustainable development. Visitors could tour commercial farms and be given opportunities to see how biofuels are grown and processed.

7.7 Plug-In Hybrid Electrics

Though the primary focus of this report is on liquid biofuel production, the emergence of plug-in hybrid electric vehicles (PHEV) in the marketplace provides another potential pathway for bioenergy to offset petroleum based transportation fuels. PHEVs are similar to hybrid electric vehicles (HEV) whose market share has grown steadily for the last several years. However, PHEVs have larger batteries which can be charged by connecting the vehicle to an electrical outlet. This means that electricity generated from biomass could be used to displace petroleum transportation fuels.

There are a number of potential advantages to utilizing electricity for transportation. First, PHEVs would be able to draw energy from the full portfolio of generation capacity including other renewables such as wind, solar, and geothermal. Since PHEVs are likely to be charged at off peak times like at night, PHEVs would likely not be as impacted as much by the availability of solar energy. However, resources such as wind and geothermal are often available at night when demand is low, thus PHEVs could help to increase utilization of these resources during off peak times. The use of biomass for power production, with its intrinsic ability to store energy in the form of feedstock, could allow Hawai'i to take advantage of the full portfolio of renewable generation to help insulate PHEV from disruptions in the supply of electricity.

Though the potential benefits of PHEV clearly could make the technology attractive in Hawai'i, it is important to acknowledge that there are obstacles to the widespread usage of PHEVs. A key obstacle is the cost of batteries which are critical to the success of the technology. Since the price of batteries is a major cost component of PHEV the cost of the vehicle will likely be directly related to amount of storage on board and the distance the car can travel before relying on liquid fuels. However, one study published by the Electric Power Research Institute (EPRI) in 2004 concluded that PHEVs have already achieved comparative lifecycle costs with traditional vehicles based on their lower fuel costs. In addition, battery prices are expected to decrease significantly as production levels increase.

The need for a new fleet of vehicles capable of using electricity is clearly a major hurdle for this mode of transportation. Since the market value of electricity is generally higher in Hawai'i than in typical mainland U.S. locations, the profitability and overall societal value of using biomass resources for electricity versus liquid fuels production is a more complex choice in terms of maximizing value for businesses and for the overall State. The viability of producing electricity and/or liquid fuels will generally depend on project-specific analyses in determining the greatest value for producers and the state of Hawai'i. It is quite possible that the most attractive approach would be to include the integrated production of biofuels and electricity at the same site.

8.0 State and National Policies and Incentives

There are a number of incentives on both the national and state levels that encourage biofuel production. Since biofuels are currently more expensive than petroleum fuels, these policies and incentives are important for the continual development of the biofuels industry. This section discusses some of the more important government incentives and opportunities for new incentives.

8.1 Federal Government Incentives

The Energy Policy Act of 2005 called for a renewable fuel standard and the U.S. Environmental Protection Agency set the rules outlining compliance for refiners, blenders and importers to meet the 2.78 volume percent renewable fuels requirement of the Act.

In 2007, H.R. 6, The Energy Independence and Security Act increased the renewable fuel standard to nine billion gallons in 2008 and progressively advances it to 36 billion gallons in the year 2022. By the year 2022, twenty-one billion gallons of the total is required to be from advanced biofuels, such as cellulosic ethanol.

The passage of the American Recovery and Reinvestment Act (ARRA, also known as the "Stimulus Bill") in 2009 provided additional incentives to the development of biofuels in the US. The majority of the incentives are in the form of research and development grants as well as loan guarantees for new projects. The direct tax incentives and usage requirements for biofuels remain unchanged. The main biofuels provisions in ARRA are the following:

- Advanced Energy Facility Investment Credit: Investment in facilities that produce equipment used in renewable energy and biofuel production is eligible for a 30 percent tax credit.
- Federal Loan Guarantees: $6 billion in federal loan guarantees are eligible on a competitive basis for advanced biofuel production that is in the development stage and has the promise to reduce greenhouse gas emissions relative to other transportation fuels.
- Research Grants: The DOE has developed plans to award nearly $800 million in federal research dollars to biofuel projects in the following areas: integrated biorefineries at the pilot and demonstration scales, commercial scale biorefineries, fundamental research of algae based biofuels, pilot plants, and demonstrations of infrastructure compatible biofuels, and finally, ethanol research.

The intent of this support is to spur development of advanced biofuels projects so that they can reach commercial maturity in a shorter period of time. Technologies that are already commercially mature, such as conventional ethanol and biodiesel production routes, would benefit little from these provisions at this time.

Table 8-1. U.S. Renewable Fuels Standard.

Calendar Year	Applicable Volume of Renewable Fuel (billions of gallons)	Significant Markers
2006	4.0	
2007	4.7	
2008	9.0	5.4 (Previous Standard)
2009	11.1	
2010	12.95	
2011	13.95	
2012	15.2	7.5 (Previous Standard)
2013	16.55	
2014	18.15	
2015	20.5	
2016	22.25	Starting in 2016 all increases must be met with feedstock other than corn starch
2017	24	
2018	25	
2019	28	
2020	30	
2021	33	
2022	36	

Source: U. S. Senate Committee on Energy & Natural Resources, H.R. 6 Energy Bill Summary Fact Sheet.

8.1.1 Agricultural Policy and Incentives

On January 1, 2008, unrestricted sugar trade began between the U.S. and Mexico under provisions of the North American Free Trade Agreement (NAFTA). Mexico produced a surplus of approximately 350,000 tons of sugar in 2007. Mexican sugar cane is among the most expensive in the world, due partly to high transport costs. In 2008 NAFTA and rulings by the World Trade organization will require that Mexico allow inexpensive corn syrup from the U.S. into its markets further impacting sugar pricing and production.[65] As recently as 1993 Mexico produced 40 million tons of raw sugar, but trade liberalization, price controls and credit costs have limited production[66] to approximately 5.6 million metric tons in 2006/07.[67]

A new USDA Biomass Crop Assistance Program provides eligible biomass feedstock suppliers with a matching dollar for dollar payment up to $45 for each ton of feedstock. This program is summarized in the text box below.

USDA Biomass Crop Assistance Program

The Biomass Crop Assistance Program (BCAP) was authorized by Title IX of the Farm Security and Rural Investment Act of 2002, as amended by Title IX of the Food, Conservation, and Energy of 2008 Act (2008 Farm Bill). BCAP:

- Assists agricultural and forest land owners and operators with matching payments for the amount paid for the collection, harvest, storage and transportation (CHST) of eligible material by a qualified Biomass Conversion Facility (BCF).
- Supports establishing and producing eligible crops for the conversion to bioenergy through project areas and on contract acreage up to 5 years for annual and non-woody perennial crops or up to 15 years for woody perennial crops. This provision will be implemented in the future.

The CHST Matching Payment Program will provide eligible material owners matching payments for the sale and delivery of eligible material to a CHST-qualified BCF. These payments will be available to eligible material owners at the rate of $1 for each $1 per dry ton paid by the CHST-qualified BCF to the eligible material owners, limited to a maximum of $45 per dry ton and limited to a 2-year payment duration.

On May 5, 2009, President Obama issued a Presidential directive to aggressively accelerate the investment in and production of biofuels. The directive included a directive that Secretary Vilsack take steps to the extent permitted by law to expedite and increase production of and investment in biofuel development efforts which includes issuance of guidance and support for collection, harvest, storage, and transportation assistance of eligible materials for use in biomass conversion facilities.

On June 11, 2009, the USDA Commodity Credit Corporation published a Notice of Funds Availability (NOFA) announcing the implementation of the 2009-CHST Matching Payment Program.

http://www.fsa.usda.gov/FSA/webapp?area=home&subject=ener&topic=bcap

8.1.2 Biodiesel and Ethanol Tax Credit

The Energy Policy Act of 2005 (Section 1344) extended the tax credit for biodiesel producers though 2008. The credit is $1.00 per gallon of agri-biodiesel and $0.50 per gallon of waste grease biodiesel. IRS Notice 2007-37 permits the co-processing of biomass with petroleum feed stocks, allowing oil companies to receive the credit by

[65] San Diego Union-Tribune, Reuters, Mica Rosenberg and Frank Jack Daniel, December 11, 2007.
[66] Federal Research Division of the Library of Congress, Country Studies, 1986 to 1998.
[67] Sugarbeet Grower Magazine, Fast Approaching: January 1, 2008, March 2007issue.

making biodiesel in their refinery operations.[68] The Energy Policy Act of 2005, Section 1345 allows a $0.10 per gallon tax credit to agri-biodiesel producers for up to 15 million gallons. To be eligible, a producer must make less than 60 million gallons per year.

The Volumetric Ethanol Excise Tax Credit (VEETC), which provides ethanol blenders/retailers with a $.51 per pure gallon tax credit, is in effect until 2010. Small ethanol producers are now defined (by the Energy Policy Act of 2005, Section 1347) as producers of up to sixty million gallons per year, up from 30 million gallons per year.

8.1.3 Alternative Fuel Infrastructure Tax Credit

Section 1342 of the Energy Policy Act of 2005 provides for a tax credit equal to 30 percent of the cost of alternative refueling property, up to $30,000 for business property. The credit is intended to financially assist those who bear extra costs of refueling station using alternative fuels including E85 and mixtures of B20 or more. The credit is set to expire December 31, 2009.

8.1.4 Alternative Motor Vehicle Credit

Light-duty lean burn diesel vehicles are eligible for a tax credit equal to 50 percent of the incremental cost of the vehicle per Section 1341 of the Energy Policy Act of 2005. IRS Notice 2006-54 establishes the procedures for manufacturers to certify to the IRS that a vehicle meets the requirements to claim the credit.

8.1.5 Clean School Bus USA

This is a Federal program of cost shared grants to help school districts implement pollution reduction measures involving their diesel bus fleet, including using biodiesel. The program is funded at $55 million for both 2006 and 2007 and is authorized for 2009 and 2010.

8.1.6 Alternative Fuel Vehicles CAFE Credit

Section 772 of the Energy Policy Act of 2005 extended the CAFE (Corporate Average Fuel Economy) credit given to alternative fueled vehicles through 2010. This incentive is up to 1.2 miles per gallon toward an automobile manufacturer's average fuel economy which helps it avoid penalties.

[68] Biodiesel Magazine, IRS Ruling on Renewable Diesel Tax Credit Fuels Debate. June 2007.

8.1.7 Cellulosic Biomass Ethanol and Municipal Solid Waste Loan Guarantee Program

The U.S. Department of Energy can issue loan guarantees to private lending institutions for up to 80 percent of the cost to construct ethanol production facilities and commercial products from cellulosic, municipal waste, and/or sugar cane. The loans must be for facility construction and the project must have at least 30 million gallons of capacity.

8.2 Hawai'i State Government Incentives

8.2.1 Hawai'i/U.S. DOE Partnership

On January 28, 2008 the U.S. Department of Energy and the State of Hawai'i signed a memorandum of understanding to set up working groups on efficiency, generation, delivery, and transportation to develop a strategic implementation plan by June, 2008 toward the goal of producing 70 percent of Hawaii's energy needs from renewable sources by 2030. DOE is committing technical and policy expertise to the project. Using local crops for producing fuel and electricity is a stated goal of the effort.

8.2.2 Alternative Fuel Development Support

The Hawai'i alternative fuel standard, enacted by Act 240 (SLH 2006) is: 10 percent of highway fuel use to be alternative fuels by 2010, 15 percent by 2015 and 20 percent by 2020. Ethanol produced from cellulosic materials is considered the equivalent of 2.5 gallons of non-cellulosic ethanol for the purposed of meeting this standard.[69]

8.2.3 State Vehicle Acquisition Requirements to Reduce Petroleum Dependency

On June 25, 2009, Act 156 was enacted, under which the procurement policy for all Hawai'i agencies purchasing or leasing light-duty motor vehicles shall be to reduce dependence on petroleum for transportation energy. Priority for selecting vehicles is to be as follows:

(1) Electric or plug-in hybrid electric vehicles;
(2) Hydrogen or fuel cell vehicles;
(3) Other alternative fuel vehicles;
(4) Hybrid electric vehicles; and

[69] U.S. Department of Energy Alternative Fuels & Advanced Vehicles Data Center, http://www.eere.energy.gov/afdc/progs/view_ind_mtx.php/tech/ALLAF/HI/0 .

(5) Vehicles that are identified by the United States Environmental Protection Agency in its annual "Fuel Economy Leaders" report as being among the top performers for fuel economy in their class.

For purposes under Act 156, "alternative fuel" means alcohol fuels, mixtures containing eighty-five per cent or more by volume of alcohols with gasoline or other fuels, natural gas, liquefied petroleum gas, hydrogen, biodiesel, mixtures containing twenty per cent or more by volume of biodiesel with diesel or other fuels, other fuels derived from biological materials, and electricity provided by off-board energy sources.

8.2.4 Ethanol Investment Tax Credit

Enacted in the year 2000, HI S.B. 2221 – Act No. 289 – 2000 provided a tax credit for investment in a qualifying ethanol production facility.

In 2004, HI S.B. 3207 – Act No. 140 – 2004 changed the above ethanol investment tax credit to the Ethanol Facility Tax Credit (EFTC). It bars other tax credits if the EFTC is claimed and limits the EFTC to investment amount. Facilities must operate at 75 percent of nameplate capacity.[70]

8.2.5 Alternative Fuel Tax Rate

Alternative fuels are taxed at a favorable rate in Hawai'i. Distributors pay a $0.025 per gallon tax for all alternatives fuels sold. In addition, they pay a license tax for each gallon sold at the rate specified in Table 8-2.

Table 8-2. Hawai'i Alternative Fuel Taxes.

Fuel Type	Tax
Ethanol	0.145 times the rate for diesel
Methanol	0.11 times the rate for diesel
Biodiesel	0.25 times the rate for diesel
Liquefied Petroleum Gas (Propane)	0.33 times the rate for diesel

Source: U.S. DOE Alternative Fuels & Advanced Vehicles Data Center

8.3 Prospects and Potential Impacts of New Incentives

The House Agriculture Committee reported farm bill (H.R. 2419) which would mandate a sugar-for-ethanol program intended to address any sugar surplus that would arise as a result of sugar imports. The U.S. Department of Agriculture (USDA) would be required to purchase as much U.S.-produced sugar as necessary to maintain market prices above established support levels. The purchased sugar would be sold to bioenergy producers for processing into ethanol. H.R. 2419 has passed the U.S. House (July 2007) and Senate (December 2007) with somewhat different versions and a conference committee of Senators and Representatives has been meeting to work out differences in the two versions. The Administration opposes limiting the USDA to disposing of sugar only for ethanol production and prefers a no Federal cost sugar program.

NAFTA-designed free trade in sugar between the U.S. and Mexico just began January 1, 2008 and the long term impact is uncertain. There is concern that inexpensive corn syrup from the U.S. market will replace sugar in Mexican soft drinks and other applications leaving either a devastated Mexican sugar industry long term or sales of Mexican sugar to the U.S. market pushing prices down there.

8.4 Opportunities for New or Modified Incentives

8.4.1 High Occupancy Vehicle Lane Incentives

The SAFETEA-LU Transportation Act, passed in 2005, directed the EPA to issue rulemaking regarding allowing single occupancy vehicles to use High Occupancy Vehicle (HOV) lanes if they are certified to be "low emission and energy efficient". On May 24th, 2007 the EPA issued proposed rulemaking for public review. One of the criteria for vehicle qualification would be that the vehicle be a "dedicated alternative fuel vehicle". If HOV programs are changed, the implementation would be by the U.S. Department of Transportation and enforcement would be by individual states.

Contra-flow (HOV) lanes such as the Kalanianaole Highway's 0.6 miles and the two-mile Nimitz Highway in Honolulu could be limited to vehicles that are energy efficient and are dedicated alternative fuel vehicles.

8.4.2 New Renewable Fuels

Work is continuing on biobased fuels other than ethanol, biodiesel and hydrogen that may be beneficial to Hawai`i. It may be advantageous for Hawai'i to develop, and encourage Federal lawmakers to develop, incentives that encourage potentially advantageous fuels that are currently in pre-commercial stages.

An example would be University of Wisconsin's development of a process that may enable more efficient mass production of DMF or 2.5-dimethyfuran. The fuel is made from sugar, has energy content equal to gasoline (higher than ethanol) and is

[70] Association of State Energy Research & Technology Transfer Institutions. *Summary of State Incentives for Biofuels* (Fall 2006).

insoluble to water in storage. Biobutanol is another example of a potential new fuel with similar advantages, especially where a mix with gasoline is needed.

9.0 Summary of Results

This report provides a means for understanding the biofuel production potential from biomass waste residues and energy crops in the state of Hawai'i. It should be noted that the estimates presented in this report often refer to maximum theoretical biofuel production potential. This maximum potential would require using all identified lands and waste materials appropriate for biofuel production. Since there are many competing uses for agricultural land, these production levels are meant to provide a starting point in understanding the potential for biofuel production in Hawai'i. It should be noted that only a fraction of the total potential is needed to meet the desired displacements for 2010, 2015, and 2020 targets.

9.1 Biofuels Production Technologies

Several biofuel production pathways were identified and characterized for this report. Efforts were made to identify benefits and constraints of the currently commercial and developing technologies that may play a role in Hawaii's energy future. Though there are a number of different biofuel conversion technologies currently under development, practical estimates for yield, cost and availability for these developing technologies are difficult to make at this time. For this reason, production estimates and cost estimates evaluated for this report focused on conversion technologies for which conversion and cost information has been the most thoroughly developed, which is for ethanol and biodiesel production. Table 9-1 below shows the technologies that were used to characterize and estimate Hawaii's biofuel production potential, as well as the feedstocks that can feed the associated conversion processes.

Several technologies are currently in research and development or demonstration phases that offer the potential to create a variety of liquid transportation fuels from biomass that more closely resemble petroleum based fuels including conventional diesel, green gasoline, and green jet fuel. However, the performance and cost information available for these options is generally at a more preliminary stage and is not particularly reliable for projecting the costs and likely market penetration for these biofuels.

Table 9-1. Commercial and Nearer Term Biomass Conversion Technology Summary.

Feedstock Type	Conversion Pathway	Product	Commercialization Status
Sugar			
Sugarcane Molasses Sweet Sorghum*	Conventional Fermentation	Ethanol	Commercial
Fiber			
Banagrass Eucalyptus Leucaena Cellulosic wastes	Enzymatic Hydrolysis and Fermentation or Thermochemical Conversion	Ethanol	Near Commercial; Demonstration Phase
Oil			
Oil Palm Jatropha Waste Fats, Vegetable Oil & Grease	Transesterification	Biodiesel	Commercial

Notes:
* Due to sparse data availability, sweet sorghum production potential was not investigated for this effort.

One factor that has an appreciable impact on the economics of biofuel production is the scale of a production facility. This issue is of particular importance in Hawai'i where geography imposes constraints on resource availability and transport of solid biomass feedstocks. These constraints were taken into consideration in developing cost estimates for biofuels production in Hawai'i. Detailed cost estimates for cellulosic ethanol production recently updated by the National Renewable Energy Laboratory (NREL) showed cellulosic ethanol conversion costs in the range of $0.92 per gallon (on a levelized basis) by the year 2012 for large biochemical-based conversion facilities designed to process 2,200 tons per day of biomass feedstock (NREL, 2009). By comparison, the base case for this analysis uses a conversion cost estimate of $1.36 per gallon for Hawai'i. This estimate adjusts for economy-of-scale issues with the expectation that in Hawai'i, 500 to 800 tons per day may be a more likely scale for facilities based on acreage and transport constraints. This conversion cost also factors in some cautiousness with respect to progress in reducing advanced biofuel conversion costs.

9.2 Biofuels from Biomass Residues

There are opportunities to significantly increase biofuel production in Hawai'i using available biomass residues. Table 9-2 shows the potential for ethanol, biodiesel, and methane production using Hawai'ian waste resources.

Table 9-2. Total Hawai'i Biofuel Potential from Waste.

Biofuel Type	Feedstock	Total Hawai'i Potential
Ethanol	Cellulosic wastes	90 million gallons/yr*
Ethanol	Molasses	5 million gallons/yr
Biodiesel	Waste oil	2.0 – 2.5 million gallons/yr
Hydrogen	Landfill gas	290 million scf/yr**

Notes:
* Represents a middle number common to both thermochemical and biochemical potentials.
** Assumes no waste is diverted from H-POWER.

From Table 9-2 it can be seen that the majority of available potential comes from cellulosic wastes (municipal solid waste, sugar cane trash, and forestry residues). With total 2007 gasoline consumption in Hawai'i at 477 million gallons per year (MGY), ethanol from cellulosic wastes could be used to displace up to 12.5 percent of the current fuel usage (on an equivalent gallons of gasoline basis).

To obtain the quantities of biomass resources that will be needed to meet the combined future Hawai'i biofuel mandates for all transportation fuels; diesel, gasoline, and (possibly) aviation fuel, producers will need to turn to energy crops in addition to available Hawai'ian residues.

9.3 Land Availability

In order to estimate energy crop production potential, the amount of land suitable for energy crop production was investigated and estimated for this effort. Hawai'i has about 300,000 acres of prime irrigated land and roughly 800,000 acres of non-prime rainfed land which has been identified as appropriate for energy crop production. Since the amount of available agricultural land in Hawai'i is not likely to increase in the future, this is an important parameter for examining biomass production potential. New crops and agricultural practices will likely lead to incremental increases in yield but the amount of land available for production of crops will likely remain static or decrease with time as development on the island continues. Table 9-3 shows prime and nonprime land for each island.

Table 9-3. Hawai'i Agricultural Lands by Island (acres).							
	Hawai'i	**Maui**	**Molokai**	**Kauai**	**Oahu**	**Lanai**	**Total**
Nonprime Rainfed Lands	652,836	90,386	38,492	20,468	12,319	6,575	814,501
Prime Irrigated Lands	97,679	65,893	11,126	53,020	55,919	16,741	300,378
Total	750,515	156,279	49,618	73,488	68,238	23,316	1,114,879

9.4 Biofuel Production from Energy Crops

Information regarding land availability and theoretical crop yields were used to develop an estimate of the theoretical production potential for energy crops. Table 9-4 below shows the maximum theoretical potential for each crop examined in this study. It should be noted that the yield values displayed in Table 9-4 are not additive. Instead the values in Table 9-4 assume that each crop is planted on all 300,000 acres of prime land and 800,000 acres of nonprime land.

Table 9-4. Hawai'i Energy Crop Potential.			
	Non-prime Land Potential	**Prime Land Potential**	**Total Theoretical**
Ethanol Crops	(million tons/year)	(million tons/year)	(million tons/year)
Sugarcane	3.2*	11.2*	14.4*
Banagrass	3.7	9.4	13.1
Eucalyptus	3.6	2.8	6.4
Leucaena	1.2	3.2	4.4
Biodiesel Crops	(million gal/year)	(million gal/year)	(million gal/year)
Oil Palm	32.4	66.3	98.7
Jatropha	16.1	62.0	78.1

Note:
(*) Yields for sugarcane expressed in green or wet tons. All other values reported in bone tons. Moisture content for sugarcane can be approximated as 67 percent.

9.4.1 Biofuel Production Optimization

Analysis performed by the University of Hawai'i indicated that biomass yield could be maximized by growing Banagrass in warmer/lower elevations and Eucalyptus in cooler/higher elevations. In addition, it appears that these fiber crops are likely more economically favorable over oil seed crops. Based on these results, fiber crops are believed to offer the most attractive energy crop option for the state and for producers alike. Table 9-5 shows theoretical biomass yields and resulting biofuel and energy production potential assuming all identified lands were used for the production of fiber crops.

Table 9-5. Maximum Energy Crop Potential and Biofuel Yield.

	Hawaii	Maui	Molokai	Kauai	Oahu	Lanai	Total
Rainfed Land Potential							
Banagrass (1000s dry tons/yr)	1,610	606	264	258	211	66	3,015
Eucalyptus (1000s dry tons/yr)	2,493	53	6	0	0	0	2,552
Irrigated Land Potential							
Banagrass (1000s dry tons/yr)	1,378	2,446	455	1,832	1,978	502	8,589
Eucalyptus (1000s dry tons/yr)	718	47	6	3	45	53	873
Total Biomass (1000s dry tons/yr)	6,199	3,151	731	2,093	2,234	621	13,349
Energy Potential							
Ethanol* (million gal./yr)	**496**	**252**	**58**	**167**	**179**	**49**	**1,202**
Co-Generation** (MW)	**126**	**64**	**15**	**43**	**46**	**13**	**306**

Notes:
* Assumes conversion factor of 80 gallons of ethanol per dry ton of cellulosic biomass
** Co-generation potential of ~2.55 kWh/gal of ethanol with enzymatic hydrolysis technology

From Table 9-5 it can be seen that the theoretical potential of ethanol from energy crops grown on all identified prime irrigated and nonprime rainfed lands is approximately 1.2 billion gallons per year. In comparison to biodiesel production from oil seed crops the potential for cellulosic ethanol is clearly much greater. For example, it was found that maximum oil seed production would occur if Jatropha were grown on prime land and Oil Palm grown on nonprime lands, resulting in a total yield of 94 million gallons of vegetable oil. This amount of oil could be converted into approximately 85 million gallons of biodiesel. On an energy basis, full production of biodiesel crops would only yield approximately 11 percent of the energy that full production of fiber crops would offer in the production of ethanol.

Another advantage of producing biofuels through cellulosic energy processes is that electricity can be generated as a co-product. For example, if enzymatic hydrolysis technology is used to convert the cellulosic biomass to ethanol, unconverted lignin from the process can be used as a boiler fuel to generate ~2.55 kWh of electricity for every gallon of ethanol produced from cellulose. This type of conversion process is just beginning the early commercialization phase of development.

9.4.2 Ethanol Breakeven Costs

Banagrass was found to offer the highest ethanol production potential per acre (1,720 gallons/acre/year) and Oil Palm was found to be the oil seed crop with the highest biodiesel production potential (203 gallons/acre/year). Feedstocks used for producing ethanol also were found to have lower feedstock costs (per gallon and per 1,000 Btu) than oil seed crops evaluated for the production of biodiesel. Breakeven costs for ethanol from Banagrass and Leucaena would be in the $2 to $2.25 range, depending on the type of land used. The costs for producing Banagrass on irrigated prime land were found to be somewhat lower than for producing this crop on rainfed non-prime land. Producing ethanol from Sugarcane and Eucalyptus lead to slightly higher break even costs, but prices are still comparable to the lower costs cellulose crops, as shown in Table 9-6 below.

Table 9-6. Breakeven Costs for Fiber and Sugar Crops.

Crop	Prime Irrigated Land ($/gallon)	Non-prime Rainfed Land ($/gallon)
Leucaena		2.03
Banagrass	1.94	2.10
Sugarcane	2.13	2.40
Eucalyptus		2.63

In general, the economics for producing biodiesel from oil seed crops is unlikely to be attractive in Hawai'i unless significant crop yield improvements are achieved through R&D, or unless economics are improved through new marketing strategies to sell non-fuel co-products from oil seed processing.

9.5 Potential Process Improvements

For this report the base-case cellulosic ethanol conversion rates were assumed to be 80 gallons per dry ton of biomass feedstock, based on the anticipated performance for this technology in the next four to seven years. Future conversion rates of 100 gallons per dry ton of feedstock may be achievable. Improvements in conversion yields for cellulosic ethanol are one way that biofuel production estimates have the potential to improve. Higher yields per ton of dry biomass would also improve the economics of ethanol production for all fiber feedstocks.

The base-case conversion cost for cellulosic ethanol production used in this analysis was $1.36 per gallon of facility processing capacity. This takes into account adjustments for ethanol facility development costs in Hawaii including construction, labor costs, and economy-of-scale factors. Note that estimates of these conversion costs are still quite preliminary, since the initial first-of-a-kind commercial facilities are only now being constructed.

For both the biochemical and thermochemical ethanol production routes, technical improvements may be able to lower the conversion cost of ethanol by roughly 35 percent from where they are today. The higher cost of feedstock in Hawai'i will make realization of breakeven selling prices of ethanol this low a challenge; even assuming 100 gallons of ethanol per ton of biomass, it is unlikely that breakeven prices below $2 per gallon will be possible.

While it is likely that the downward trend in production costs will continue for cellulosic ethanol conversion technologies, it should be noted that this may be impaired by current economic condition. There is some level of risk in bringing new technologies to commercialization and while some might see this as an opportunity, it is possible that this may lead to a lag in development.

10.0 Conclusions

The results of this study demonstrate that Hawai'i has the resources necessary to meet the Renewable Fuel Standard (RFS) that has been laid out in Act 240, SLH 2006. Meeting this target will require a focused effort to address and optimize energy crop species and conversion technology pathways.

10.1 Biofuels Potential from Waste Residues and Energy Crops

There is a potential to produce biofuels from Hawaii's existing waste streams; however, energy crops will be needed to meet the State's RPS targets. Ethanol produced from cellulosic wastes streams could be used to displace up to 12 percent of the current gasoline consumption. However, biodiesel produced from waste fats, oils and greases would account for less than half of one percent of current diesel fuel usage.

Table 10-1 shows the estimated maximum biofuel potential from waste residues and dedicated energy crops in Hawaii. Since the anticipated yields of ethanol from biomass feedstocks are fairly well known, the maximum amount of ethanol that could be produced was estimated, in terms of gallons and Btu's of this biofuel. For advanced biofuel technologies that produce green gasoline, green diesel and green jet fuel, the anticipated gallons of fuel that will be produced per ton of biomass feedstock are still being refined. In order to estimate the amount of these fuels that could be produced, a useful approach is to assume that the efficiency of converting Btu's of feedstock into Btu's of liquid fuel will be somewhat similar for the different biofuel conversion pathways. This approach was used to provide the estimates shown in the table below, adjusting for the higher Btu content of gasoline, diesel, and jet fuels relative to ethanol.

Table 10-1. Maximum Theoretical Hawai'i Biofuel Production Potential

Feedstock	Biofuel 10^{12} Btus/yr	Ethanol million gal/yr	Green Gasoline equivalent million gal/yr	Green Diesel equivalent million gal/yr	Green Jet Fuel equivalent million gal/yr
Energy Crops	101	1,202	786	722	751
Cellulosic Wastes	8	95	62	57	59
Total:	109	1,297	848	779	810

The production levels shown in Table 10-1 assume utilization of all identified agricultural land and unused biomass wastes/residues. Table 10-1 does not include yet-to-be-determined production of feedstocks such as algae, which could be produced on land that is not agriculturally zoned. Since there are many competing uses for agricultural land, these production levels are meant to provide a broad maximum starting point in understanding the potential for biofuel production in Hawaii. However, only a fraction of the total potential is needed to meet the desired displacements for 2010, 2015, and 2020 targets in the State of Hawai'i Act 240.

The maximum theoretical case for potential biofuels production potential in Hawai'i can serve as an important baseline to compare current consumption levels against. Table 10-2 below compares current fuel usage to the energy content in the maximum theoretical biofuel production case (cellulosic ethanol and fiber crops).

Table 10-2. Hawai'i Fuel Consumption, 2007.

Fuel	Fuel Consumption* (million gal/yr)	Energy Content (Btu/gal)	Percent of Maximum Biofuel Potential for Energy Crops
Gasoline	475	128,900	8%
Diesel (on & off highway)	66	140,300	2%
Jet Fuel	449	135,000	12%
Total All Petroleum Uses	2,222	135,000	59%

* Source: Energy Information Administration, U.S. DOE

From Table 10-2 it can be seen that displacing 20 percent of the gasoline consumption in Hawai'i would require about 8 percent of the maximum theoretical potential from energy crops. Displacing 20 percent of the diesel fuel would require a biofuel production capacity of approximately 2 percent of the maximum theoretical potential from energy crops. Meeting the State's goals under Act 240 for displacing 20 percent of gasoline and diesel fuel consumption combined, would require dedicating about 10 percent of the potential land available for energy crop production, based on the use of high-yielding energy crops. To gain a perspective on related land use issues, it can be noted that the Hawaii BioEnergy members collectively oversee 150,000 acres of land that they are evaluating for the production of energy crops and bioenergy products. The magnitude this land area is equivalent to 13.5 percent of the total Hawai'i agricultural land area identified for potential production of energy crops (i.e., 810,000 acres of non-prime and 300,000 acres of prime land, as noted earlier). Overall, it appears that meeting the State's goals under Act 240 for displacing 20 percent of gasoline and diesel fuel consumption with biofuels seems quite achievable.

10.2 Recommendations for Further Study

There are a number of ongoing efforts in Hawai'i and around the world that are working to advance the science of biofuel production. It will be important to monitor the progress of the technologies evolving from these efforts to help identify those that are most worthy of pursuing in Hawai'i.

- **New crops**: Algae and sweet sorghum are two examples of crops which may hold significant promise for the state of Hawai'i. Unfortunately at the time this analysis was performed, adequate data was not available to make assumptions regarding yield or biofuel potential for these crops. Further investigation into these crops, as well as continuing efforts to identify other potentially promising crops, will help maximize biofuel production potential and lead to a greater understanding of best practices.
- **Crop trials**: Testing and breeding of indentified crops will lead to a greater understanding of the potential, agricultural techniques and the economics of energy crop production in Hawai'i.
- **Economies of scale**: It has been noted that restrictions to biomass supply that result from Hawaii's geography may result in higher biofuel costs due economy-of-scale factors. Additional investigation would be useful regarding island-specific constraints that will determine the quantities of energy crops that can be aggregated in specific locations given the distribution of agricultural acres, land ownership patterns, and road transport constraints. This information could be used in conducting R&D to identify and optimize conversion technologies for the scale(s) of biomass feedstock supplies likely to be available in Hawai'i from energy crop plantations.
- **Agricultural methods**: New agricultural methods of integrated food and fuel production such as alley cropping may also offer some promise to increase yields and reduce concerns over food versus fuel conflicts.
- **Biorefining and high value production of coproducts**: New models of producing multiple products from biomass at a single site have the potential to enhance the economics of biofuel production. The production of biofuels, electricity, commodity chemicals and animal feed from a microalgae production facility is one example of the potential of these integrated biorefinery models.
- **Collaboration large land owners:** Hawaii's three largest landowners have organized to form Hawai'i Bioenergy LLC to explore Hawaii's biofuel production potential. Active cooperation between landholders and researchers will help to advance the science of energy crop production in the state. In addition,

cooperation will help to facilitate a free flow of information between interested parties. (www.hawaiibioenergy.com)

10.3 Obstacles

Though the potential for developing biofuels technologies has been highlighted, there is of course inherent risk in planning around technologies which are not yet commercially mature. It is always possible that issues such as concerns about the economy or changing public perception about the benefits of biofuels may inhibit investment. In turn this could delay the advancement and commercialization of developing biofuel production technologies as those with capital avoid risk and adopt a business as usual mindset. For this reason, fossil fuel displacement strategies will need to be adaptive to take advantage of the technologies as they become available.

10.4 Crops Specific Considerations

It is important to recognize potential benefits and drawbacks of energy crops considered in this evaluation. Sugar crops have been grown commercially in Hawai'i for decades. This means there is a significant amount of knowledge, as well as identified lands and equipment, for harvesting and processing sugarcane. In addition, food, biofuel, and usable electricity are all potential products of sugarcane. For these reasons, sugarcane production in is seen as one viable option as a feedstock for bioenergy production in Hawaii.

In order for oil seed crops such as Oil Palm and Jatropha to be competitive in Hawai'i, R&D would be needed to achieve higher yields per acre, reduce harvesting costs, and/or develop high-value co-products.

According to the analysis performed by the University of Hawai'i, Banagrass could be an attractive energy crop in Hawai'i, based on both potential yields and economics. One challenge is the difficulty in finding locations in Hawai'i where Banagrass will flower and seed. This poses a challenge for plant propagation and efforts to improve yields for this crop, which need to be explored further to confirm the promise for banagrass in Hawaii as a major energy crop alternative.

Sweet sorghum could offer strong potential as an energy crop for Hawaii. This crop alternative is in a relatively early stage of evaluation, and reliable data on its production potential was not available for this effort. Sweet sorghum readily produces seeds in Hawaii; and, with the potential for planting and harvesting two to three crops per year of sorghum in Hawai'i, this should enhance the ability to breed high-yielding varieties of sorghum that produce more tons per year of sugar and fiber per acre.

Biofuel production from microalgae is in the early stages of development. Researchers are still working to identify appropriate strains and develop production techniques that are not susceptible to invasive microorganisms or lower yielding algae strains that may be problematic. Most commercially produced algae is cultivated in raceway ponds which require level horizontal surfaces; the option of developing thousands of acres of algae ponds in Hawai'i is a distinct challenge, since much of the terrain is sloped. As noted earlier, algae has a number of advantages, including being able to use non-fresh water. In addition, algae can be used to capture waste carbon dioxide from the exhaust of power facilities.

10.5 Final Observations

It should be quite achievable for biofuels produced from in-state resources to displace 20 percent of the gasoline and diesel fuel needed for vehicle transportation in Hawai'i. This could be accomplished using about 10 percent of available agricultural land for energy crop production to supply the required biomass feedstock.

There are a variety of energy crops and biofuel conversion technologies that could be economically viable in Hawai'i. The State's unique and varied geography, microclimates, and infrastructure provide challenges in selecting and/or developing crops and conversion technologies for commercially viable production of biofuels. Efforts in the past to help the Hawaiian sugarcane industry address these state-specific challenges provide a useful model for the needs of an emerging biofuel industry in Hawai'i. The Hawaiian Sugar Planters' Association (now the Hawaii Agriculture Research Center (HARC)) developed sugarcane varieties that were adapted to 13 different environments in Hawai'i in order to address the range of microclimates and crop production challenges found in the State. A similar effort to identify and optimize energy crops for the varied environments in Hawai'i would help increase the likelihood that biofuel development reaches its full potential in offsetting petroleum dependency and fostering economic development centered on a new biofuel industry in Hawai'i.

The U.S. Department of Energy (DOE) and the National Renewable Energy Laboratory (NREL) are engaged in a major initiative to support the development of advanced biofuel conversion technologies in the U.S. With their expressed interest in seeing Hawaii become a model for bioenergy production, they could play a valuable role in ongoing efforts to identify and optimize conversion technologies suited to the economy-of-scale and varied requirements for biofuel development and expansion in Hawai'i.

In addition, identifying opportunities where some combination of biofuel, food, electricity, and high value products can be produced at the same facility could help make biofuel economics more favorable in specific circumstances.

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Appendix A. Detailed Economic Analysis Assumptions for Sugarcane and Banagrass

Ethanol Production from Sugarcane on Irrigated Prime Lands

Items	Unit	Quantity	Cost and Revenue 1999	Cost and Revenue 2007	Annual Equivalent Cost and Revenue
1. Land preparation	Acre	1	$506.00	$612.53	$292.84
Machinery					
Labor					
2. Planting	Acre	1			
seeds	Acre	1	$50.00	$60.53	$28.94
Machinery					
Labor					
Chemicals					
Other					
3. Field operations					
Machinery					
Labor					
Fertilizer	Acre	1	$114.00	$138.00	$65.98
Herbicides	Acre	1	$297.00	$359.53	$171.89
Pesticides					
Irrigation	Acre	1	$486.00	$615.57	$601.61
other					
4. Harvesting	Acre	1	$480.00		$290.07
Machinery					
Labor					
Other	Acre	1			
5. Other operations	Acre				
6. Operating overhead	Acre		$193.30	$178.62	$145.13
Total costs	Acre	1	$2,126.30	$1,964.77	$1,596.46
Fixed cost for machinery	Acre	10%		$196.48	$159.65
Total variable cost	Acre	1		$1,768.29	$1,436.81
A. Production of sugarcane					
1. Primary production (per acre/crop)	Tons	104.00			
2. Secondary production (Silage)					
3. Gross revenue	$/acre		$35.82		$1,780.84
B. Net revenue from sugarcane					
Net revenue	acre/year			-$1,964.77	$184.38

A. Production of sugar ethanol					
1. Processing cost (sugar ethanol)	$/gallon	$1.07			
2. Total processing cost	$/acre				$1,082.28
3. Total production cost	$/acre				$2,678.74
Gross revenue from sugar ethanol	gal/acre	2,028.00			$2,435.41
C. Net revenue from sugar ethanol	$/acre				-$243.33
B. Production of cellulose ethanol					
Transportation cost (sugarcane trash)					
Burn sugarcane	$/acre		$30.77		$18.59
Operating overhead (burn sugarcane)	$/acre	10%			$1.86
Sugarcane trash yield					
Burn sugarcane (acre/crop)	Tons	17.68			
Cellulose ethanol yield (burned sugarcane)					
a. Conversion (67 gallons/ton)	gallon/ac	1184.56			
b. Conversion (80 gallons/ton)	gallon/ac	1414.40			
c. Conversion (100 gallons/ton)	gallon/ac	1768.00			
Processing cost (cellulose ethanol)	$/gallon	$1.36			
Total processing cost: burned sugarcane					
a. processing cost (67)	$/acre				$804.25
b. processing cost (80)	$/acre				$960.30
c. processing cost (100)	$/acre				$1,200.37
Total production cost: sugar plus cellulose ethanol					
Total production cost: burned sugarcane					
a. Total production cost (67)	$/acre				$3,503.44
b. Total production cost (80)	$/acre				$3,659.49
c. Total production cost (100)	$/acre				$3,899.56
Total Gross revenue (cellulose plus sugar ethanol)					
Gross revenue (burned sugarcane)					
a. Gross revenue (67)	$/acre	3212.56			$3,857.93
b. Gross revenue (80)	$/acre	3442.40			$4,133.94
c. Gross revenue (100)	$/acre	3796.00			$4,558.58

B. Net revenue from ethanol					
Net revenue: burned sugarcane	acre/year				
a. Net revenue (67)	$/acre				354.49
b. Net revenue (80)	acre/year				474.45
c. Net revenue (100)	acre/year				659.02
Burned Sugarcane					
Feedstock cost of ethanol (67)	$/gallon				$1.01
Feedstock cost of ethanol (80)	$/gallon				$0.94
Feedstock cost of ethanol 100)	$/gallon				$0.85
Feedstock cost of ethanol (67-110)	$/gallon				$0.81
Break even price of ethanol (67)	$/gallon				$2.18
Break even price of ethanol (80)	$/gallon				$2.13
Break even price of ethanol (100)	$/gallon				$2.00
Break even price of ethanol (67-110)	$/gallon				$1.91

Notes: Sugarcane

1. Cost of production data are based on Kinoshita and Zhou (1999). Note: machinery and labor costs are included in the respective operation category (e.g., land preparation, harvesting etc.).
2. Prices were inflated to 2007 using appropriate CPI difference between 1999 and 2007.
3. Cost of irrigation was included for the analysis as sugarcane production was considered for irrigated prime lands.
4. Operating overhead is assumed to be 10% of total operational cost.
5. Sugarcane yield estimation for irrigated prime lands (warm moist regime) based on Ogoshi (2008).
6. Sugarcane planting cycle is every two years.
7. Price per ton of sugarcane ($ 34.09) is based on National Agricultural Statistics Service data for 2004. Prices were inflated to 2007 using appropriate CPI for Honolulu.
8. Two types of ethanol production from sugarcane were considered. Type 1 is the sugar ethanol and type 2 is the cellulose ethanol from sugarcane trash.
9. Sugarcane trash was estimated for unburned and burned sugarcane fields separately.
10. Transportation cost for sugarcane trash was estimated based on transportation cost of a ton of dry matter of Banagrass.
11. Gallons of ethanol per ton of sugarcane = 19.5 (Shapouri et al. 2006).
12. Ethanol yield for a ton of sugarcane trash (67 gallons) was based on Gieskes and Hackett (2003). Variable conversion rates were considered as follows:

    Scenario 1: Conversion rate of ethanol per ton of dry matter = 67 gallons
    Scenario 2: Conversion rate of ethanol per ton of dry matter = 80 gallons
    Scenario 3: Conversion rate of ethanol per ton of dry matter = 100 gallons

Scenario 4: Variable conversion rates of ethanol per ton of dry matter over time. For 1-5 years (67/65 gallons), for 6-10 years (80 gallons), for 11-15 years (90 gallons), for 16-20 years (100 gallons), for 21-25 years (110 gallons)

13. Processing cost for sugarcane = $ 0.063/pound of raw sugar equivalent in 2005$. 1 gallon = 14.77 lbs, therefore processing cost/gallon = 14.77 x 0.063 = $0.93 (Shapouri et al. 2006). Inflating to 2007$ = $ 0.93 x 1.06 = $0.98 (inflation factor = average US CPI 2005-2007) and adjusted to the prices in Honolulu by multiplying by a factor of 1.083 (CPI adjusted factor for Honolulu as compared to the US average) = $ 1.069/gallon.
14. Economic analysis was conducted for a 24 year period to represent complete crop cycles.
15. Price of ethanol in 2007 is $2.405523/gallon. This is rounded to $2.41/gallon
16. Cost and revenue figures may differ slightly due to rounding.

Ethanol Production from Banagrass on Irrigated Prime Lands

Items	Unit	Quantity	Cost and Revenue 1999	Cost and Revenue 2007	Annual Equivalent Cost and Revenue
1. Land preparation	Acre	1	$126.00	$159.50	$34.94
Machinery					
Labor					
2. Planting					
Seeds	Acre	1	$6.00	$7.60	$1.66
Machinery					
Labor					
Chemicals					
Other					
3. Field operations					
Machinery					
Labor					
Fertilizer	Acre	1	$148.50	$187.98	$187.98
Herbicides	Acre	1	$111.00	$140.51	$140.51
Pesticides					
Irrigation	Acre	1			
Other					
4. Irrigation	Acre		$324.00	$410.15	$410.15
4. Harvesting	Acre	1	$219.00	$277.23	$277.23
Machinery					
Labor					
Other	Acre	1	$177.00	$224.06	$224.06
5. Other operations	Acre	1	$224	$282.92	$282.92
6. Operating overhead	Acre	1	133.5	$169.00	$155.95
Total costs	Acre	1	$1,468.50	$1,858.95	$1,715.40
Fixed cost for machinery	Acre	4.44%		$82.46	$76.09
Variable cost	Acre	1		$1,776.49	$1,639.31
A. Production of Banagrass					
1. Primary production**	tons/ac/year	37.00			
2. Secondary production					
3. Gross revenue per acre	Acre			$3,102.83	$3,102.83
B. Net revenue from Banagrass					
Net revenue	acre/crop			$1,243.88	$1,387.42
Net revenue	1.5 crops/year			$1,865.82	$2,081.14
C. Production of ethanol					

Processing cost	$/gallon	$1.36			
a. processing cost (67)	$/acre	2479.00		$3,371.44	$3,371.44
b. processing cost (80)	$/acre	2960.00		$4,025.60	$4,025.60
c. processing cost (100)	$/acre	3700.00		$5,032.00	$5,032.00
a. Total production cost (67)	$/acre			$5,230.39	$5,086.84
b. Total production cost (80)	$/acre			$5,884.55	$5,741.00
c. Total production cost (100)	$/acre			$6,890.95	$6,747.40
a. Gross revenue (67)	$/acre			$5,963.29	$5,963.29
b. Gross revenue (80)	$/acre			$7,120.35	$7,120.35
c. Gross revenue (100)	$/acre			$8,900.44	$8,900.44
C. Net revenue from ethanol					
a. Net revenue (67)	$/acre			$732.90	$876.45
b. Net revenue (80)	$/acre			$1,235.80	$1,379.35
c. Net revenue (100)	$/acre			$2,009.49	$2,153.03
Feedstock cost of ethanol (67)	$/gallon				$0.69
Feedstock cost of ethanol (80)	$/gallon				$0.58
Feedstock cost of ethanol 100)	$/gallon				$0.46
Break even price of Banagrass	$/ton				$46.36
Break even price of ethanol (67)	$/gallon				$2.05
Break even price of ethanol (80)	$/gallon				$1.94
Break even price of ethanol (100)	$/gallon				$1.82

Notes: Banagrass

1. Cost of production data are based on Kinoshita and Zhou (1999). Note: machinery and labor costs are included in the respective operation category (e.g., land preparation, harvesting etc.).
2. Prices were inflated to 2007 using appropriate CPI for Honolulu.
3. Cost of land preparation includes both soil preparation and planting Banagrass.
4. Cost for other operations included road maintenance, crop control research, equipment, landholding etc.
5. Cost of irrigation was included for the analysis as Banagrass production was considered for irrigated prime lands.
6. Operating overhead is assumed to be 10% of total operational cost.
7. Average price of a ton of Banagrass dry matter ($80) was based on Kauai Island Utility cooperative. Renewable energy technology assessment report, March 21, 2006 (URL: http://www.kiuc.coop/pdf/KIUC%20RE%20Final%20Report%207%20-%20Biomass%20&%20MSW.pdf).
8. Banagrass yield estimation for irrigated prime lands (warm moist regime) based on Ogoshi, R. 2008.

9. Ethanol yield for a ton of Banagrass dry matter (67 gallons) was based on Gieskes and Hackett (2003). Variable conversion rates were considered as follows:

   Scenario 1: Conversion rate of ethanol per ton of dry matter = 67 gallons
   Scenario 2: Conversion rate of ethanol per ton of dry matter = 80 gallons
   Scenario 3: Conversion rate of ethanol per ton of dry matter = 100 gallons
   Scenario 4: Variable conversion rates of ethanol per ton of dry matter over time. For 1-5 years (67/65 gallons), for 6-10 years (80 gallons), for 11-15 years (90 gallons), for 16-20 years (100 gallons), for 21-25 years (110 gallons)

10. It is assumed that harvesting cycle of Banagrass is 8 months.
11. Processing cost for Banagrass is assumed to be the same as ethanol produced from corn stover. Total processing ethanol from lignocellulose source like corn stover = $1.50/gallon less $0.49 stover cost/gallon (McAloon et al. 2000) = $1.01/gallon

    (in 1999$).The processing cost for Banagrass ethanol processing inflated to 2007$ by a factor of 1.24 = $ 1.255 (US CPI average 1999-2007) and adjusted to the price in Honolulu by multiplying a factor of 1.083 (CPI adjusted factor for Honolulu as compared to the US average) = $ 1.36.
12. Price of ethanol in 2007 is $2.405523/gallon. This is rounded to $2.41/gallon
13. Cost and revenue figures may differ slightly due to rounding.