Assessment of Dependence of State of Hawaii on Oil

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EXECUTIVE SUMMARY

Section 355 of the Energy Policy Act of 2005 (EPAct) directs the Secretary of Energy to assess the dependence of the State of Hawaii on oil, and to prepare (in consultation with agencies of the State of Hawaii and other stakeholders, as appropriate) and submit to Congress a report describing the findings, conclusions, and recommendations resulting from the assessment.

Hawaii is almost entirely dependent on oil imported to its islands for electricity, transportation, and other energy uses. As of 2006, Hawaii relied on oil for nearly 90% of its energy needs. Hawaii also has the highest electricity costs in the United States, and some of the highest gasoline prices in the country. In terms of pricing, average daily regular-grade gasoline prices have increased by 115% for the State of Hawaii since 2003, increasing from a low of $1.78/gallon in January 2003 to a high of $3.96 in June 2008[1]. This is higher than the national average of $3.76. According to the Energy Information Administration (EIA), Hawaii has the highest electricity prices in the country at 18.7¢/kWh (kilowatt hour) compared with the national average of 8.8¢/kWh.

Because all petroleum resources are imported to the state, it is particularly vulnerable to supply disruptions and/or price variability. As evidenced by the close correlation of electricity price changes to oil price changes during the past two decades, the economic relationship between oil-fired generation of electricity and refined petroleum products for transportation was found to be tightly coupled. Further, disruptions in the oil supply would impact the electricity sector (and, subsequently, dependent industries such as tourism), as the state currently relies on oil for 83% of its electricity generation. The timing of oil supply disruption impacts would depend on available storage and the ability for the state to import refined product.

The economic relationship between oil prices and the economy of Hawaii is complex. Hawaii has experienced positive growth in its gross state product (GSP) for the past 10 years, even in light of increased oil prices. However, this growth appears to have slowed with recent sharp increases in oil prices. While the percentage of state expenditures on fossil fuel products is relatively low at 1.4% (compared to 4.8% nationally in 2005), the growth in GSP has decreased from a high of 10% from 2003 to 2004 to approximately 6% from 2005 to 2006 as oil prices have increased from $30/bbl to $100/bbl. The analysis in this report identifies several economic areas that would be most impacted if the supply of oil to the state was disrupted—a disruption that could be mitigated by greater reliance on indigenous energy generation.

In particular, initial assessments have identified renewable resources in Hawaii with the potential to generate more than 2,000 MW nameplate capacity. Inclusion of distributed solar power from rooftops increases the total to more than 4,000 MW nameplate capacity. For general sense of scale, the current installed electric generation nameplate capacity in Hawaii is 2,414 MW, though these capacity figures cannot be directly compared as the variability of wind and solar generation leads to lower energy output on average than the current installed generation mix. Further, while the island of Oahu consumes nearly 60% of the state's electricity and is not electrically

[1] EIA. The retail price of $3.96 per gallon includes Hawaii state gasoline taxes of $0.17 per gallon. The U.S. average retail price of $3.76 per gallon includes average state gasoline taxes of $0.214 per gallon.

interconnected with the outer islands, less than 60 MW of the identified renewable potential is located on Oahu. .

Ultimate technical and economic viability of the majority of this potential—wind and solar resources—will depend on solutions to the challenges of maintaining grid stability and reliability with increasing variable generation, and developing business models via legislative, regulatory, and utility action that appropriately support renewable energy development. The small scale of most individual island power grids and current lack of interconnection among the islands pose unique technical and commercial challenges for significant use of renewable power sources. These factors will require careful attention to stability, power quality, and energy storage challenges, as well as overall grid reliability. In addition, increases in renewable energy contribution will be subject to constraints of site selection, as well as residents' consumer preferences as well as environmental, aesthetic, and cultural sensitivities.

Another alternative to crude oil imports for Hawaii's energy needs is imported natural gas. The assessment concluded that there are a number of possible advantages and challenges to pursuing natural gas imports to Hawaii. Significant capital investment and at least three years to build the necessary infrastructure would be required as no liquefied natural gas (LNG) import facility exists in the state today. If LNG were imported, the share of primary energy supplied by petroleum could be reduced by approximately 20% within four to seven years of a decision to move forward. Natural gas may be obtained from a variety of supply sources, including Australia or domestic sources such as Alaska. The electric utilities could retain the ability to consume fuel oil in the event of an LNG supply disruption, thereby further enhancing energy security. However, the small market size of the state, the limited growth potential, and the expense and difficulty of establishing a receiving terminal were identified as the main disadvantages of Hawaii as an LNG market.

The use of biofuels and hydrogen for transportation was found to be technically feasible for a few select pathways:

Ethanol:

- Four crop scenarios were investigated: 1) sugar cane grown on all soils suitable for sugar, 2) leucaena and eucalyptus grown on all soils suitable for trees, 3) sugarcane grown on all soils suitable for sugar; and leucaena and eucalyptus (as a second priority), grown on remaining soils suitable for trees, and 4) banagrass grown on all soils suitable for sugar. The third crop scenario produced the most ethanol for each of the scenarios with a maximum value slightly greater than 700 million gallons of ethanol per year. For comparison, the total motor gasoline sales in Hawaii in 2005 totaled 454 million gallons, or 668 million gallons of ethanol on an energy-equivalent basis. Results indicate that Hawaii, Maui, and Kauai counties collectively could potentially produce enough ethanol to match their current gasoline energy demand using select agricultural lands of importance to Hawaii.
- Maui and Kauai counties could also potentially meet gasoline demand with ethanol produced from sugar cane, and Kauai would have a surplus of 28 million gallons.

- Sugarcane for ethanol production would further offset fossil fuel use in the electricity sector in Hawaii. The net oil reduction for ethanol facilities would be a combination of both the oil displaced by the ethanol fuel produced and utility fuel oil displaced by electricity cogenerated by the ethanol production facilities and sold to the utilities.
- Impacts of ethanol production on food prices and supply were not examined.

Biodiesel:

- Biodiesel production is currently 700,000 gallons, based on waste oil feedstock. Estimates of biodiesel production potential range from 2-2.5 million gallons from waste oil, and up to 160 million gallons from dedicated crops by 2030. However, it was noted that only small experimental plantings of suitable crops are currently grown, and that the biodiesel estimate was independent of the ethanol estimate.

Hydrogen:

- Hydrogen could be produced from indigenous resources such as geothermal, solar, wind, hydro, and biomass, or from imported LNG (if available).
- Projected fueling costs indicate that as a fuel, hydrogen produced from biomass, geothermal, wind, and LNG may be economically competitive with gasoline. However, further evaluation of the infrastructure requirements is necessary to determine technical feasibility and total investment costs.
- Because hydrogen can be produced from any primary energy source, the abundant renewable resources available on the Hawaiian Islands provide significant potential to produce the hydrogen that could meet Hawaii’s transportation needs.

A program that seeks to reduce Hawaii’s oil dependence and provide 70% of the state’s primary energy from clean energy sources by 2030 is the Hawaii Clean Energy Initiative (HCEI). HCEI was established by the U.S. Department of Energy and the State of Hawaii through a memorandum of understanding (MOU) signed in January 2008. HCEI activities will be concentrated in two areas: 1) HCEI Working Groups will be formed and made up of private, state, and U.S. government experts in the areas of Transportation and Fuels, Electricity Generation, Energy Delivery and Transmission, and End-Use Efficiency. These groups will formulate policy recommendations, project proposals, and seek paths to economic transformation; and 2) Partnership Projects will be undertaken with local and mainland partners that demonstrate and commercialize new technologies and relieve technical barriers. The initiative ultimately seeks to incentivize intelligent investments by capital markets, energy suppliers, and energy consumers; penetrate the market with existing and new clean energy technology at significant scale; accelerate new investment in the energy sector to achieve rapid asset turnover; and improve energy service delivery and energy security.

If Hawaii is successful in its HCEI efforts, it could serve as an integrated model and demonstration test bed for how to expand the penetration of renewable energy and strategically reduce oil dependence. Reduction in oil consumption may result in positive economic, environmental, and energy security gains for the state.

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ABBREVIATIONS AND ACRONYMS

AEO	Annual Energy Outlook (from Energy Information Administration)
ALISH	Agricultural Lands Important to the State of Hawaii
Bbl	Barrel (of oil)
Btu	British Thermal Unit
CNG	Compressed Natural Gas
CSP	Concentrating Solar Power
DES	Delivered Ex-Ship
DOE	U.S. Department of Energy
E85	Motor fuel with 85% ethanol, 15% gasoline
EIA	Energy Information Administration
EPAct	Energy Policy Act of 2005
FFV	Flex-fuel Vehicle
FOB	Free On Board
GIS	Geographic Information Systems
GSP	Gross State Product
HCEI	Hawaii Clean Energy Initiative
HECO	Hawaii Electric Company
HELCO	Hawaii Electric Light Company
HFCTF	Hawaii Fuel Cell Test Facility
HHC	Hawaii Hydrogen Center
HNEI	Hawaii Natural Energy Institute, University of Hawaii
kW	Kilowatt
kWh	Kilowatt-hour
LLO	Large Land Owners
LNG	Liquefied Natural Gas
LSFO	Low-sulfur Fuel Oil
MECO	Maui Electric Company
MMBtu	Million British Thermal Units
MOU	Memorandum of Understanding
MSW	Municipal Solid Waste
MW	Megawatt
MWe	Megawatt electrical
NRCS	Natural Resource Conservation Service
NREL	National Renewable Energy Laboratory
PEM	Polymer Electrolyte Membrane
PV	Photovoltaic
RPS	Renewables Portfolio Standard
SOH	State of Hawaii
ZA	Zoned Agricultural

1. Introduction

Hawaii is located on an isolated island archipelago in the United States. This isolation creates certain challenges regarding energy supply and security. Through 2007, Hawaii relied on oil for nearly 90% of its energy needs. All petroleum resources are imported to the state, thereby suggesting that it is particularly vulnerable to supply disruptions and/or price variability. Hawaii also has the highest electricity costs in the United States.

Section 355 (a) of the Energy Policy Act of 2005 (EPAct) directs the Secretary of Energy to assess the economic implications of the dependence of the State of Hawaii on oil. Section 355 (b) authorizes the Secretary to contract with qualified public or private entities in order to carry out the assessment. Section 355(c) requires the Secretary of Energy to prepare (in consultation with agencies of the State of Hawaii and other stakeholders, as appropriate), and submit to Congress, a report describing the findings, conclusions, and recommendations resulting from the assessment. The specific language of Section 355 can be found in Appendix B of this report.

2. Background

In compliance with Section 355(c), this report summarizes the findings, conclusions, and recommendations of several assessments that were conducted to fulfill the legislative requirements. This report also includes information from other publicly available assessments that contain information pertinent to the requirements of Subsections 355 (a) and (b). The specific assessments conducted to inform this report include:[2]

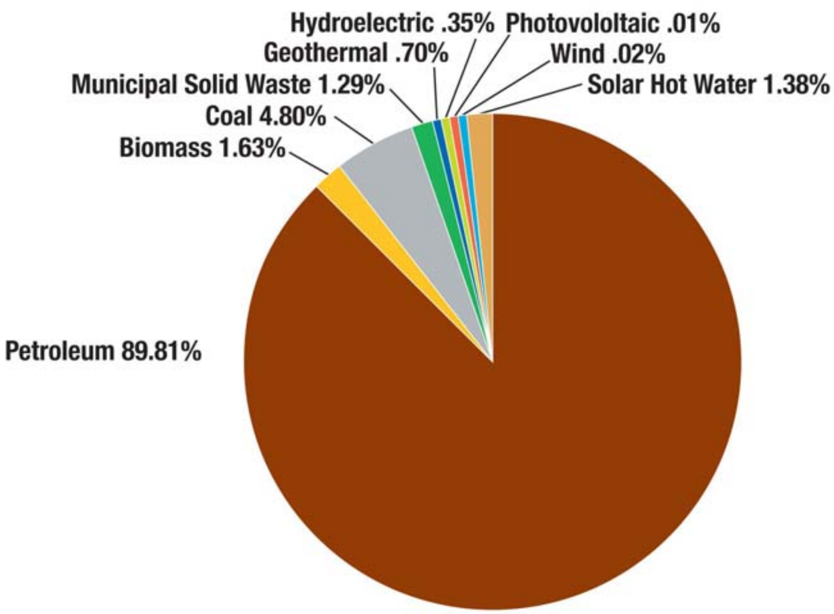
1. **"Current State of Hawaii's Energy Resources and Utilization,"** by Terry Surles and Milton Staackmann (Hawaii Natural Energy Institute)
2. **"Analysis of the Impact of Petroleum Prices on the State of Hawaii's Economy,"** by Makena Coffman, Terrence Surles, and Denise Konan (Hawaii Natural Energy Institute)
3. **"Relationship of Refinery Operations and Oil-Fired Generation,"** by Terry Surles (based on material developed by FACTS, Inc. in report No. 5)
4. **"Renewable Power Options for Electricity Generation: Molokai Case Study Leading to State-wide Analysis,"** by Peter Lilienthal, Alicen Kandt, Blair Swezey (National Renewable Energy Laboratory – NREL), and Terry Surles (Hawaii Natural Energy Institute)
5. **"Evaluating Natural Gas Options for the State of Hawaii,"** FACTS, Inc.
6. **"A Scenario for Accelerated Use of Renewable Resources for Transportation Fuels in Hawaii,"** by Michael Foley, Scott Turn, Milton Staackmann, and Terry Surles (Hawaii Natural Energy Institute).

[2] All reports are available at www.eere-pmc.energy.gov/hawaii.aspx.

3. Prospects for Crude Oil Supply Disruption and Price Volatility and Potential Impacts on the Economy of Hawaii

3.1 The Current Energy Situation in Hawaii

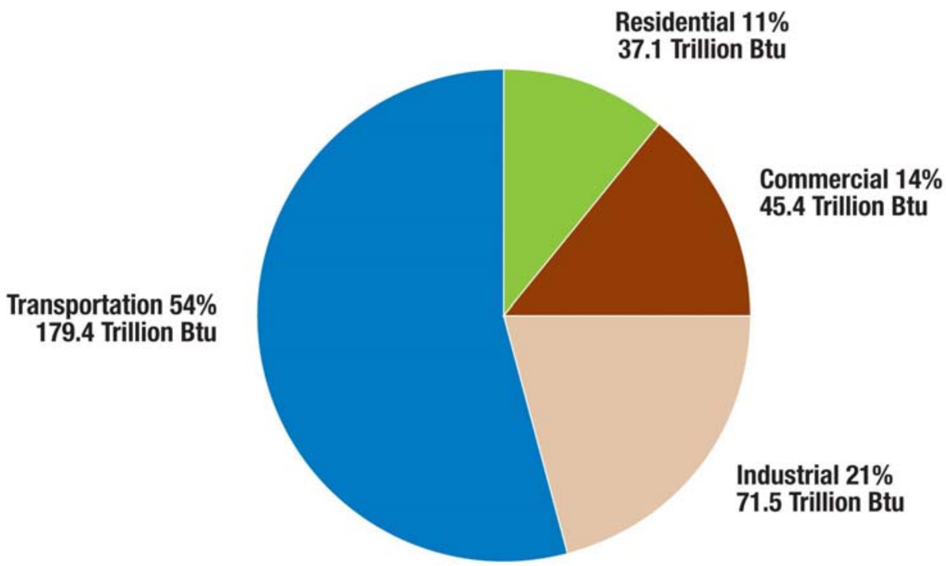
Nearly 90% of Hawaii's primary energy is derived from petroleum products, with small amounts of energy provided by other resources (see Figure 1). For example, coal is imported and used to produce some electricity. In terms of alternative energy, biomass and solar hot water heating currently represent the largest proportion, though they still represent a small fraction of the total at 1.63% and 1.38% of total primary energy consumption, respectively.



Source: State of Hawaii Strategic Industries Division

Figure 1. State of Hawaii primary energy sources (2005). Total primary energy consumption was 333.4 trillion Btu

End-use demand by sector is shown in Figure 2. Transportation represents the largest proportion of demand at 54%, followed by the industrial sector at 21%. Residential energy demand represents the smallest proportion at 11%.

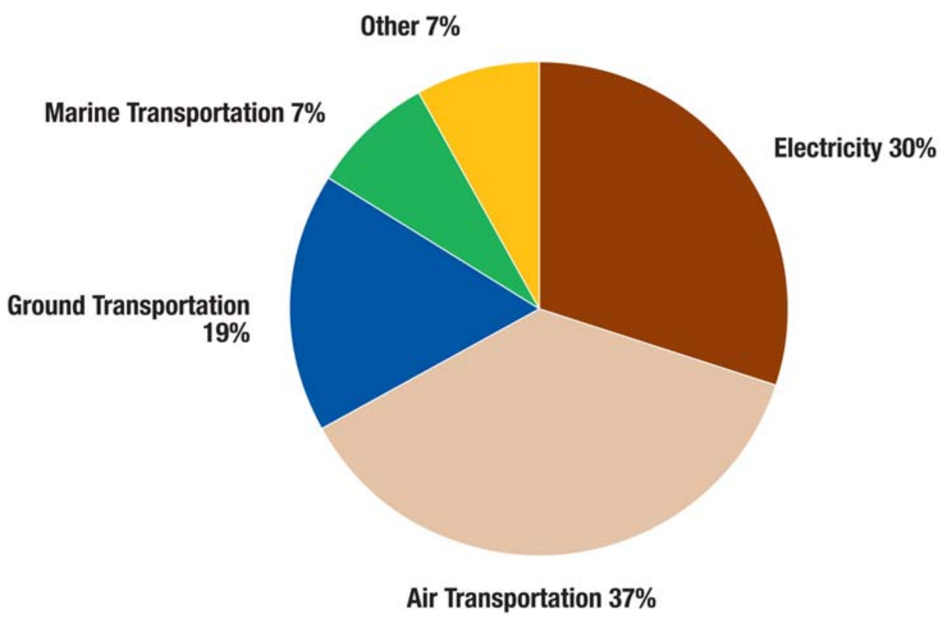


Source: EIA State Energy Data, 2005

Figure 2. State of Hawaii energy demand by sector. Total demand was 333.4 trillion Btu (2005)

Residential, industrial, and commercial sectors predominantly consume energy in the form of electricity, of which 83% is produced by fuel oil generators.

Transportation energy demand represents 63% of all the state's petroleum demand, and includes ground, marine, and air transportation (see Figure 3).



Source: State of Hawaii Energy Resource and Utilization

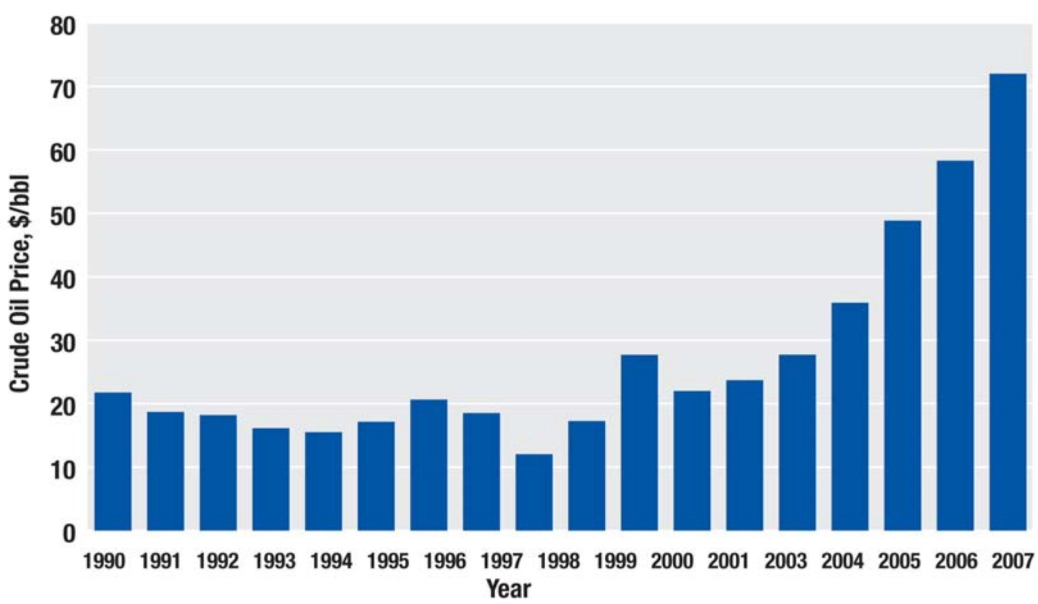
Figure 3. State of Hawaii petroleum energy consumption by end use. Total consumption was 284.42 trillion Btu (2003)

State law is driving change in the energy economy of Hawaii.

- In 1994, Act 199 (Session Laws of Hawaii [SLH] 1994) created a 10% ethanol content requirement for gasoline, which took effect in April 2006[3].
- Act 240 (SLH 2006) created an alternative fuel standard (AFS) for the state, with a goal to provide 10% of highway fuel demand from alternate fuels by 2010, 15% by 2015, and 20% by 2020.
- Hawaii's renewable portfolio standard (RPS), established by Act 95 (SLH 2004), requires that 20% of net electricity sales come from renewable energy by 2020 (it includes biofuels as a renewable energy source). The RPS law also sets milestones of 10% by 2010, and 15% by 2015.
- In 2008, the State of Hawaii entered into an MOU with DOE to achieve 70% of their energy needs from "clean" sources by 2030.
- In support of the aforementioned goals, the state provides an investment tax credit for ethanol equal to 30% of nameplate capacity per year for the first 40 million gallons, a reduction in state and local fuels taxes (a weighted average of $0.21/gal ethanol and $0.26/gal biodiesel), and a $0.05/gal state government procurement preference for biodiesel.

3.2 Oil Pricing

U.S. oil prices have nearly quadrupled during the past 17 years from about $20/bbl in 1990 to $77/bbl in 2007 (see Figure 4). At the time of this writing, the price per barrel has been consistently trading above $100/bbl.[4]



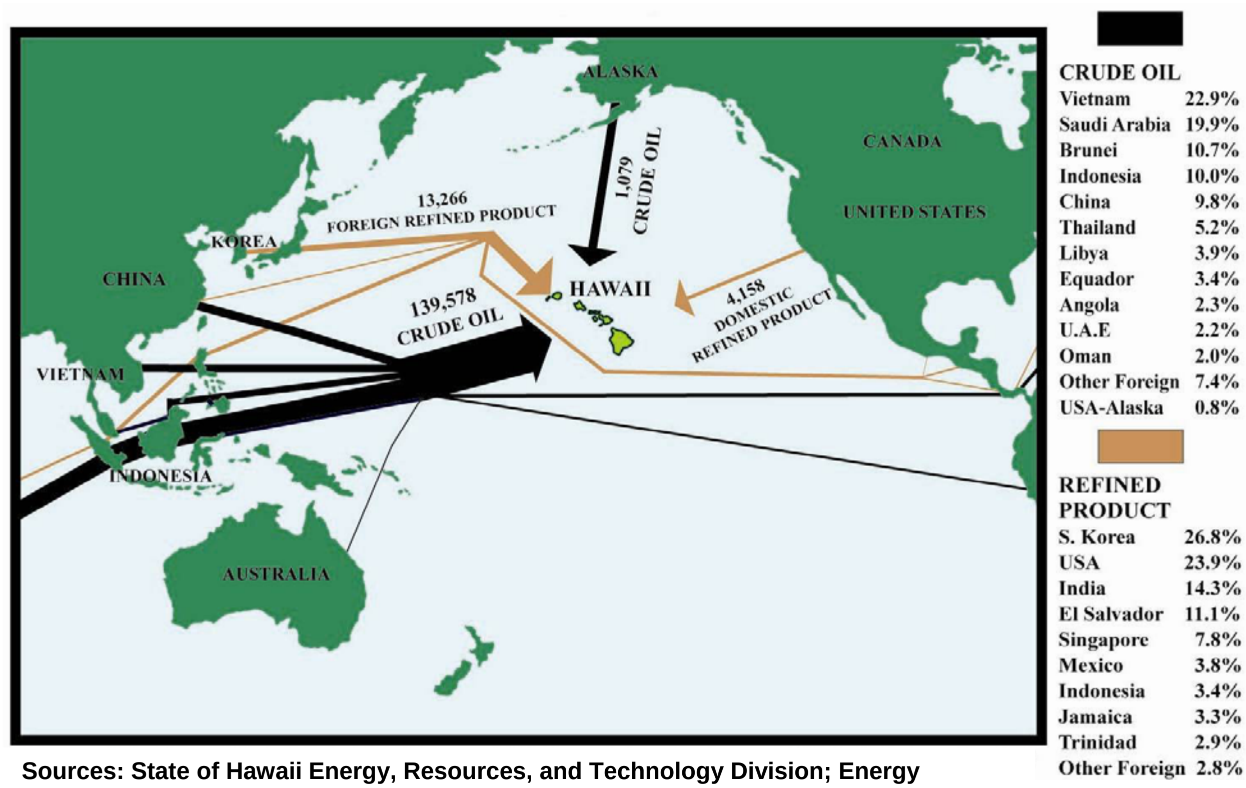
Source: Energy Information Administration

Figure 4. Crude oil pricing (unadjusted for inflation)

[3] It should be noted that no commercial ethanol production facilities are operational in Hawaii at this time.
[4] On July 1, 2008, crude oil (West Texas Intermediate) spot prices were $140 per barrel.

3.3 Oil Supply Issues – Crude and Refined

Both crude oil and refined petroleum products are shipped into Hawaii from Alaska and California (and possibly from Washington) or imported from Asia. Refined products (almost exclusively jet fuel) come from Korea and mainland refineries. Figure 5 illustrates the movement of petroleum and crude oil to the state.



Sources: State of Hawaii Energy, Resources, and Technology Division; Energy Information Administration – (preliminary May 2007)

Figure 5. Petroleum Movements into Hawaii as of 2007

Two refineries operate in the state, on the Island of Oahu: Chevron Hawaii and Tesoro. In 2006, the state imported more than 51 million barrels of oil, or approximately 141,670 barrels per day (EIA 2006). The refinery utilization rate was approximately 98%.. According to the Energy Information Administration (EIA), the daily refining capacity was 147,500 barrels of crude oil in 2007. Figure 5 shows the contributions from Alaska and from the major countries supplying crude oil to Hawaii.

Domestic levels of petroleum shipments to Hawaii (primarily from Alaska) have decreased from 44% in 1992 to 1% in 2006. Imports from Middle East sources increased from 0.4% in 1992 to 24.1% in 2006. The biggest increases during that time came from Vietnam, China, Brunei, and Saudi Arabia. More than six million barrels of refined oil products were also shipped to Hawaii in 2006. Of these imported refined products (primarily jet fuel), about 24% came from the continental United States, with most of the remainder coming from Asian sources. According to EIA's storage statistics, Hawaii has 35,000 barrels of reserve motor gasoline and 589,000 barrels of distillate fuel oil available.

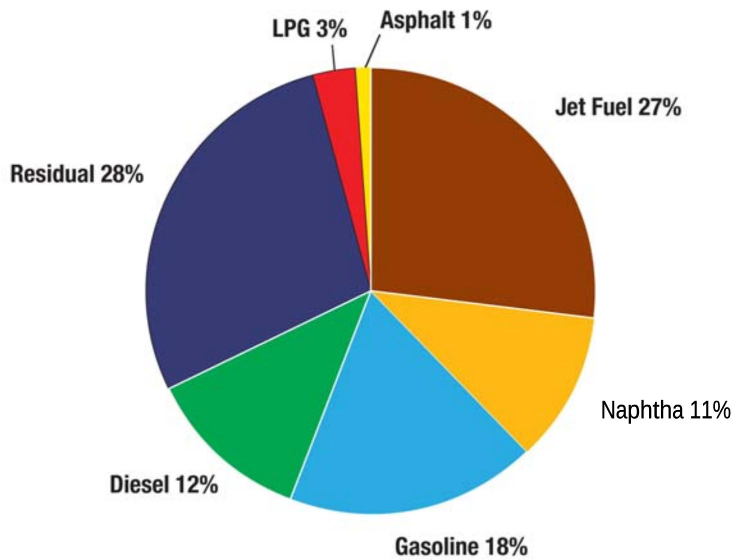
3.4 Oil Products Use in Hawaii

Almost 90% of total energy use in Hawaii in 2005 involved petroleum products, compared to about 40% in the United States, overall. On a per-capita basis, Hawaii's total energy consumption is among the lowest in the country. However, Hawaii uses considerably more oil per person than the U.S. average—about 40 barrels per person in a year, compared to the U.S. average of 23 barrels

The following are other important aspects of the energy situation in Hawaii (Hawaii Electric Company (HECO) 2006):

- Fuel oil accounts for 28% of Hawaiian oil consumption compared to 4% for the United States, on average. The large demand in Hawaii is due to the statewide electrical generating use, 83% of which is oil-fired generation.
- Jet fuel has the largest demand share of oil in Hawaii, accounting for 31% of petroleum demand vs. 9% for the United States, on average. Refined jet fuel is imported to the state, as well as crude oil, and thus has a higher share of overall demand that is greater than the locally refined share (27%) of imported crude oil (Figure 6).
- Gasoline is 18% of petroleum demand in Hawaii, compared to 48% of total oil demand in the United States.

Crude oil imported to Hawaii is primarily used for transportation (ground, marine, and air), then electricity generation, followed by industrial use (see Figure 6).

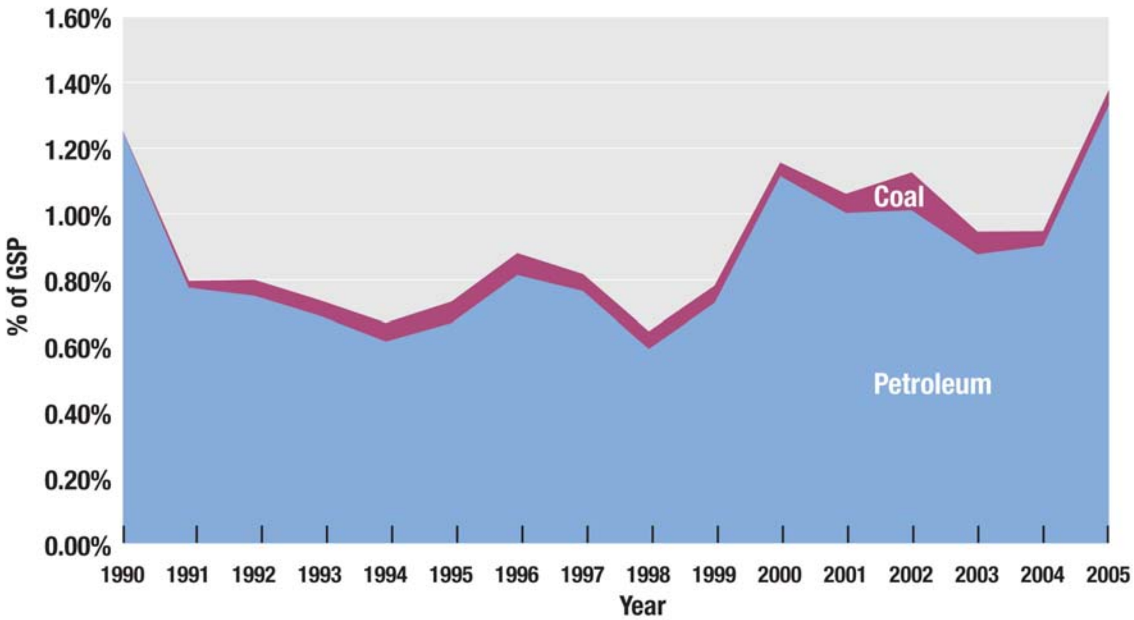


Source: HECO 2006

Figure 6. Oil products refined from a barrel of crude oil in Hawaii (2006)

3.5 Gross State Product and its Interrelationship to Oil Supply

Historically, as shown in Figure 7, fossil fuel expenditures have accounted for less than 2% of Hawaii's GSP during the past few decades. In 2005, fossil fuel expenditures represented 1.4% of Hawaii's GSP, compared to 4.8% for the entire United States. This lower share is derived from relatively fewer oil product-related industries and the higher share of tourism and services industries within the state of Hawaii. There is some indication that increased oil prices are impacting the state economy. For example, the relative share of GSP spent on fossil fuel expenditures has increased sharply since 2003, as oil prices have risen from $30/bbl in 2003 to $100/bbl today. Further, the growth of Hawaii GSP has dropped from a high of 10% from 2003 to 2004 to approximately 6% from 2005 to 2006 as oil prices have increased.



Source: Bureau of Economic Analysis and EIA

Figure 7. Fossil fuel expenditures as a percentage of Hawaii's gross state product

3.5.1 Volatility Analysis

Consistent with historical observations noted above, recent volatility analysis indicates that oil price volatility will have significant economic impacts (Coffman et al. 2007). In the short run, the economic analysis indicates that a 10% increase in world oil prices would decrease real gross state product by 0.5%, and increase inflation by 0.16%. This is consistent with recent decreases in GSP growth as oil prices have increased.

Analyses of long-run impacts imply that the economy may be strongly impacted over time. That is, analysis indicates that oil prices (e.g., differences between EIA Annual Energy Outlook 2006 high and low oil price scenarios)[5] have increasing negative effects on the economy as the price of oil increases over time. As shown in Figure 8, the analysis calculated potential decreases in state real domestic gross product ranging from $650 million in 2010 to nearly $2 billion in 2025. The reduction of nearly $2 billion in GSP between the high and low AEO oil price projections in 2025 corresponds to a 2.9% reduction. These analyses do not explicitly estimate effects of rising oil prices on the level of tourism based on air travel cost increases, which could lead to potentially large additional state economic impact.

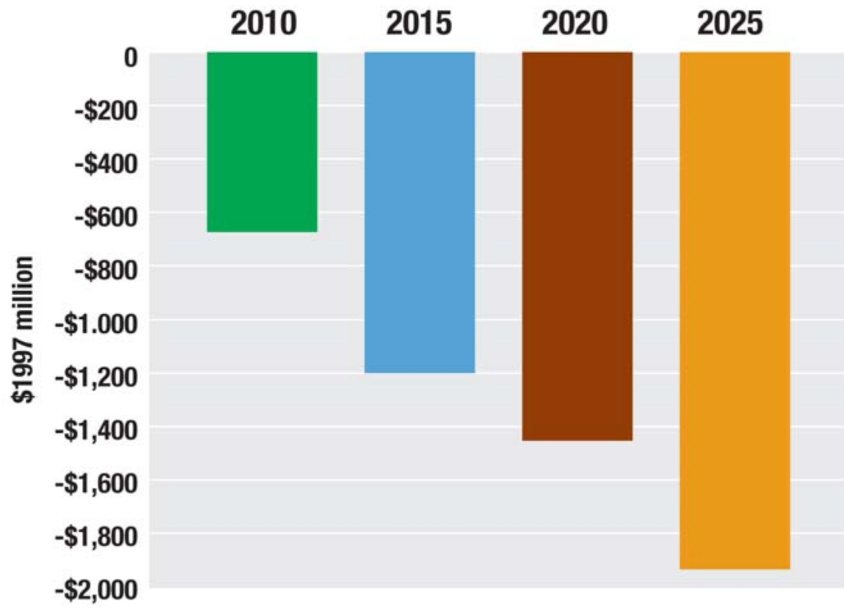


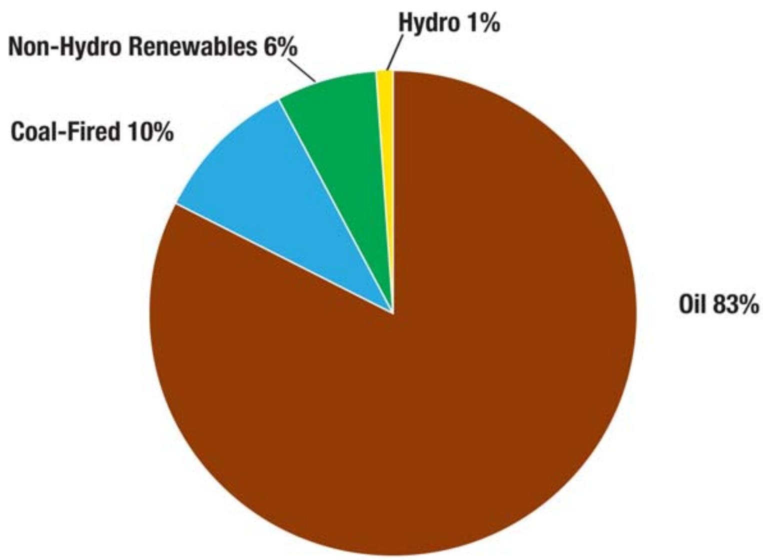
Figure 8. Reduction in Hawaii's real gross state product (from 2010 to 2025) calculated between scenarios using AEO 2006 high and low oil price projections ($1997 million)

3.6 Prospects for Crude Oil Supply Disruption and Potential Impacts on the Economy of Hawaii

3.6.1 Impacts on Electricity Generation

To better understand how oil disruption would affect electricity prices, a closer look at generation is required. According to EIA's most recent state energy profile (2006 edition), the statewide electrical generating capacity is 2,414 megawatts (MW)—83% is oil-fired generation, 10% is coal-fired, 1% is from hydroelectric systems, and approximately 6% is derived from non-hydro renewable energy, including wind, photovoltaic systems, geothermal, municipal solid waste (MSW), and biomass combustion. While solar hot water heating is not necessarily considered part of the electric generation system, it is listed here as a renewable resource, primarily because the data are presented in this manner and most water-heating devices in the state are electric (see Figure 9).

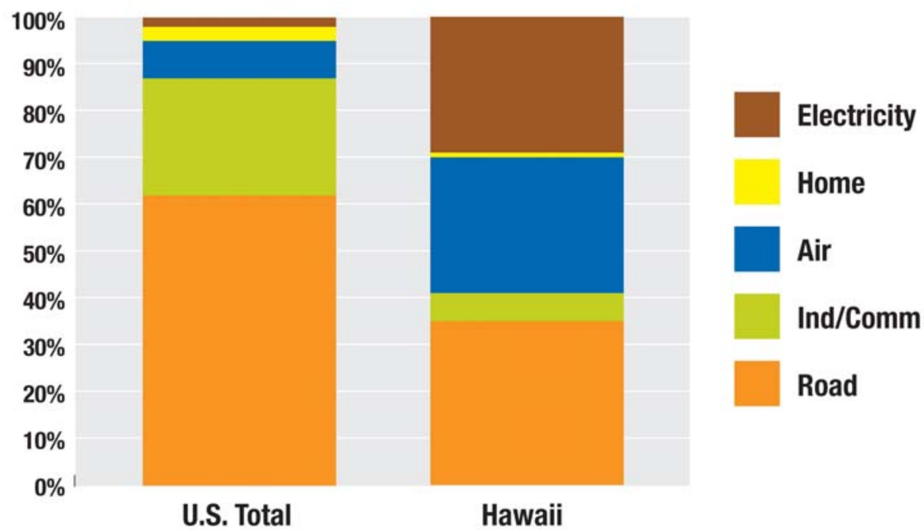
[5]Oil prices in EIA AEO 2006 Oil Price Scenarios were as follows: (year: low, high.) 2010: $64, $87; 2015: $51, $107; 2020: $49:$119; 2025: $49, $126.



Source: EIA

Figure 9. Hawaii electricity capacity by type. Total capacity 2,414 MW (2006)

As a percentage of end use, oil represents more of an impact on electricity when compared with the rest of the United States (see Figure 10). Hawaii's dependence on oil for electricity generation suggests that a disruption in the supply of this resource would have a significant impact on electricity generation.



Source: "Evaluating Natural Gas Options for the State of Hawaii," FACTS Inc.

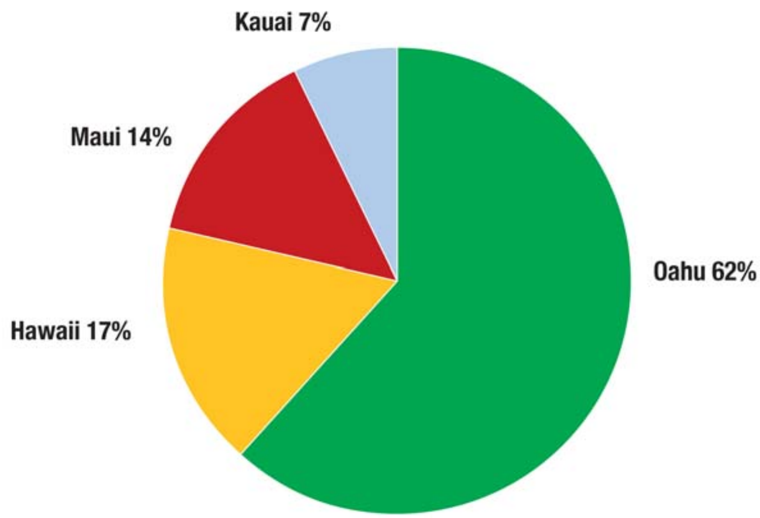
Figure 10. Oil demand by end use (2003)

According to EIA's storage statistics, Hawaii has 589,000 barrels of distillate fuel oil available, or approximately a 30 day supply to support oil-based electricity generation and other uses at full capacity. If only electricity generation were supported by stored distillate fuel oil, approximately 180 days of generation could be supplied.

3.6.2 Impacts on Transportation

Ground Transportation. Gasoline use in Hawaii has grown by almost 25% during the past 15 years. In 1992, the state used about 380 million gallons of gasoline. By 2006, that amount increased to more than 470 million gallons.

On a county-by-county basis, the Island of Oahu (City and County of Honolulu) accounted for approximately 62% of the gasoline demand in the state, using slightly more than 290 million gallons in 2006; Hawaii County had a demand of almost 80 million gallons. Maui County (Lanai, Molokai, and Maui) had a demand of 66 million gallons, while Kauai's gasoline consumption was 34 million gallons in 2006. Figure 11 summarizes the county-by-county distribution of gasoline use (DBEDT 2006b).



Source: State of Hawaii Data Book, 2006, Table 17.16

Figure 11. Percentage of Hawaii gasoline used by county. Total gasoline use 470 million gallons (2006)

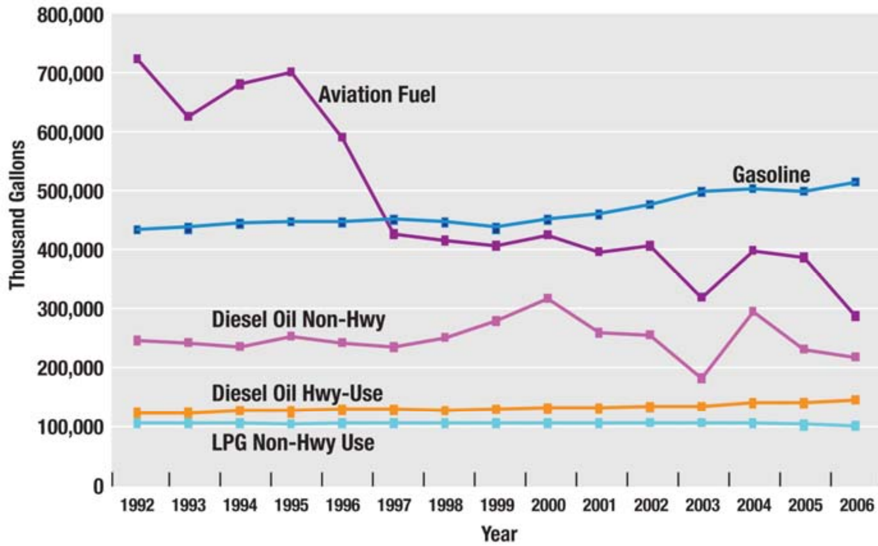
On-road diesel use amounted to approximately 4.3 million barrels in 2006, about 9% of the total petroleum use in the state. Oahu accounts for 63% of the total diesel fuel use, Hawaii County 14%, Maui 12%, and Kauai 11% (DBEDT 2006).

A small amount of liquefied petroleum gas (LPG) is used for transportation (some city and county of Honolulu vehicles), but this amounts to less than 0.1% of all petroleum liquids.

Marine Transportation. A considerable amount of residual fuel oil results from refinery operations. While most of this is used for electricity generation, approximately 10% (65 million gallons per year) is used as bunker fuel for marine shipping (DBEDT 2006a).

Air Transportation. Total jet fuel consumption was slightly more than 5 million barrels in 2006, approximately 31% of the petroleum use in the state; nationally, jet fuel accounts for approximately 10% of petroleum use. Total consumption includes jet fuel refined in the state and imported refined product. Oahu consumed 51% of the jet fuel total, Maui 29%, Hawaii County 14%, and Kauai 6% (DBEDT 2006b).

Overall, in terms of liquid fuel sales trends, aviation fuel consumption has decreased in the past decade, due partly to increasing airline fuel efficiency, while gasoline sales have seen a slight increase (see Figure 12).



Source: DBEDT 2006b

Figure 12. Liquid fuel consumption from 1992 to 2006

Reserves of transportation fuels are very limited. According to EIA's storage statistics, Hawaii has 35,000 barrels of reserve motor gasoline[6], and the state used nearly 30,000 barrels for transportation uses per day in 2006. In recognition of the unique situation of Hawaii, the Energy Conservation Reauthorization Act of 1998 (Public Law 105-388) amended the Energy Policy and Conservation Act (EPCA) (42 U.S.C. 6201, et seq.), to give Hawaii assured access to Strategic Petroleum Reserve (SPR) oil in the event of a severe energy supply interruption. Details of this provision are provided in Appendix C.

3.7 Industry-Sector Impacts from an Oil Supply Disruption

The following section describes the impacts to industry sectors that are related to the petroleum-refining and electricity sectors. The discussion focuses on impacts to industries in the state from a change in demand in the petroleum-refining and electricity sectors.

Petroleum Refineries Sector Impacts. Table 1 identifies the top 10 industries in Hawaii that rely on refined petroleum products. In the event of an oil supply disruption, these industries would be highly impacted from decreases in petroleum refinery production.

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[6] Energy Information Administration Petroleum Navigator (http://tonto.eia.doe.gov/dnav/pet/hist/mgfsxhi1m.htm). The EIA reserve gasoline stocks do not include secondary stocks held by dealers or tertiary stocks held by end users.

In addition to the expected impacts to the transportation sector (air, water, and truck transportation), the auto rental and leasing sectors (related to tourism) also would be strongly impacted from decreased availability of diesel and gasoline. Disruption also would have a significant impact on commercial buildings, waste management, and wholesale trade.

The relative degree of impact on a specific sector is indicated by the percentage of sector expenditures on petroleum products. For example, commercial and institutional buildings will be relatively less impacted than waste management (2% vs. 11%) due to less direct dependence on petroleum products.

Table 1. Top 10 Hawaii Industry Sectors Purchasing from the Petroleum Refineries Sector

Industry	% of Overall Expenditures Allocated to the Hawaii Petroleum Refining Sector	Purchases in Hawaii Petroleum Refineries Sector (million 2006 $)
Air Transportation	20.5%	428.3
Other state and local government enterprises	5.0%	130.2
Water Transportation	4.2%	95.8
Truck Transportation	10.4%	47.6
Commercial and institutional buildings	2.0%	32.9
Waste management and remediation services	11.0%	34.0
Automotive equipment rental and leasing	5.4%	24.5
Wholesale Trade	0.7%	21.3
Maintenance and repair of nonresidential buildings	2.5%	17.7
Social assistance – except child day care services	3.3%	17.5
Source: Minnesota IMPLAN Group, Commodity Balance Sheet for Petroleum Refineries, Sector 142, Hawaii		

Table 2 represents the top 10 industries in Hawaii that are vendors and suppliers to petroleum refineries. In the event of an oil supply disruption, these industries would be most impacted from decreases in petroleum refinery operations.

Table 2. Top 10 Hawaii Industry Sectors which Receive Petroleum Refineries Sector Outlays

Industry	% of Hawaii Allocation of Petroleum Refineries Sector Outlays	Hawaii Allocation of Petroleum Refineries Sector Outlays (million 2006 $)
Oil and gas extraction	1.6%	55.0
Wholesale trade	1.4%	49.6
All other miscellaneous professional and technical services	0.3%	11.8
Management of companies and enterprises	0.3%	11.1
Natural gas distribution	0.3%	10.9
Power generation and supply	0.3%	9.1
Monetary authorities and depository credit intermediaries	0.2%	7.0
Architectural and engineering services	0.2%	6.9
Legal services	0.1%	4.6
Hotels and motels	0.1%	3.6
Source: Minnesota IMPLAN Group, Industry Balance Sheet for Petroleum Refineries, Sector 142		

In addition to the expected impact to the oil and gas extraction industry, there is also a large impact in terms of potential lost revenues to the wholesale trade.

Electric-Utility Sector. Table 3 represents the top 10 industries in Hawaii that purchase electricity, ranked by expenditures. Real estate includes all properties, exclusive of hotels and motels. These industries would be highly impacted if electricity production decreases as a result of an oil supply disruption. Those industries that would be hardest hit are tourism, real estate, lodging, and restaurants/bars. The critical nature of electricity supply is not directly evident from the relative low percentages of expenditures of these industries (0.5-2% of total).

Table 3. Top 10 Hawaii Industry Sectors Purchasing from the Electricity Sector

Industry	% of Overall Expenditure Allocated to the Hawaii Electric Sector	Purchases in Hawaii Electric Sector (million 2006 $)
Real estate	1.4%	77.6
Hotels and motels	1.3%	64.3
Other state and local government enterprises	1.8%	47.2
Food services and drinking places	0.9%	32.8
Management of companies and enterprises	1.1%	15.3
Industrial gas manufacturing	1.0%	12.0
Travel arrangement and reservation services	1.6%	11.9
Wholesale trade	0.4%	11.0
Clothing and clothing accessories stores	0.9%	8.9
Food and beverage store	1.0%	7.9
Source: Minnesota IMPLAN Group, Commodity Balance Sheet for Power Generation and Supply, Sector 30		

Table 4 represents the top 10 industries in Hawaii that are vendors and suppliers to electric utilities. If there was an oil supply disruption that impacted electricity generation, these industries would be most impacted from decreased electric utility operations.

Table 4. Top 10 Hawaii Industry Sectors That Receive Electric-Sector Outlays

Industry	% of Hawaii Allocation of Electric Sector Outlays	Hawaii Allocation of Electric Sector Outlays (million 2006 $)
Petroleum refineries	1.0%	11.1
Legal services	<0.1%	4.7
Food services and drinking places	0.2%	2.1
Real estate	0.2%	2.0
Wholesale trade	0.1%	1.9
Miscellaneous professional and technical services	0.2%	1.9
Maintenance and repair construction	0.1%	1.6
Oil and gas extraction	0.1%	1.5
Rail transportation	<0.1%	1.1
Water transportation	<0.1%	1.0
Source: Minnesota IMPLAN Group, Industry Balance Sheet for Power Generation and Supply, Sector 30		

Note that electricity-sector in-state spending is less than that of the petroleum refineries sector, so the direct impact to industries in Hawaii from a decrease in electric-sector revenues is not as great. This is not the case with industries that use electricity for doing business, where impacts may be substantial—especially in the tourism sectors (see Table 3).

Employment and Economic Impacts. In terms of potential to weaken the state's economy, should an oil supply disruption occur, state economic data indicate that every $1 million decrease in demand from petroleum refineries and electric utilities would represent an estimated loss of $3.4 million in earnings statewide (Minnesota's IMPLAN Group).

4. The Economic Relationship between Oil-fired Generation of Electricity from Residual Fuel and Refined Petroleum Products Consumed For Ground, Marine, and Air Transportation

As previously stated, Hawaii has a high reliance on obtaining shipments of fossil fuels into the State,[7] deriving nearly 90% of its primary energy from petroleum products, 100% of which are shipped into to the state. This high reliance on oil for both electricity and refined products for transportation is apparent in the economic relationship among crude oil prices, electricity prices, and prices of refined petroleum products.

As shown in Figure 13, trends for electricity prices (for residential, commercial, and industrial sectors) and crude oil prices from 1990-2006 indicate a strong correlation between crude oil prices and electricity prices.

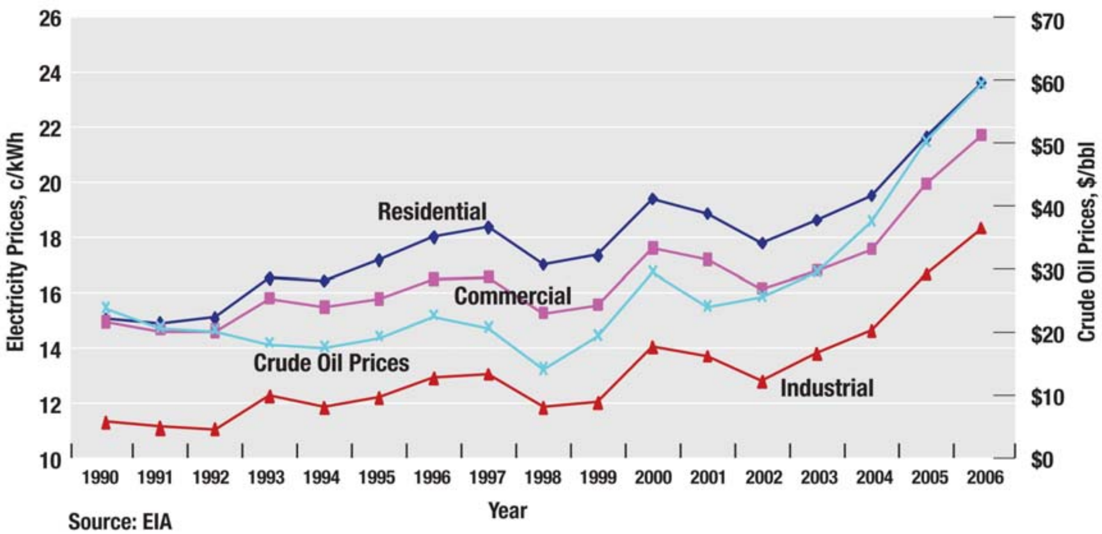

Figure 13. Average Hawaii electricity prices by sector in relation to crude oil prices (1990-2006)

When examining consumption by sector (residential, commercial, and industrial), the industrial sector experiences the lowest electricity prices relative to the other sectors. However, all sectors are impacted by crude oil prices, as shown in Figure 13. Residential electricity prices have increased from a low of 15¢/kWh in 1990 to 24¢/kWh as of 2006. It should also be noted that the state of Hawaii Administrative Rules Title 6 (State of Hawaii 2008) provides for "…increases or decreases…in rates reflecting increase or decrease…in cost incurred by electric or gas utilities for fuel and purchased energy due to changes in the unit cost of fuel and purchased energy." That is, electricity providers are allowed to pass on increased fuel prices directly to the consumers.

Additionally, even as prices have increased in the past years, electricity consumption has shown long term growth (see Figure 14).

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[7] The impact of supply disruption was assessed as part of FACTs 2003.

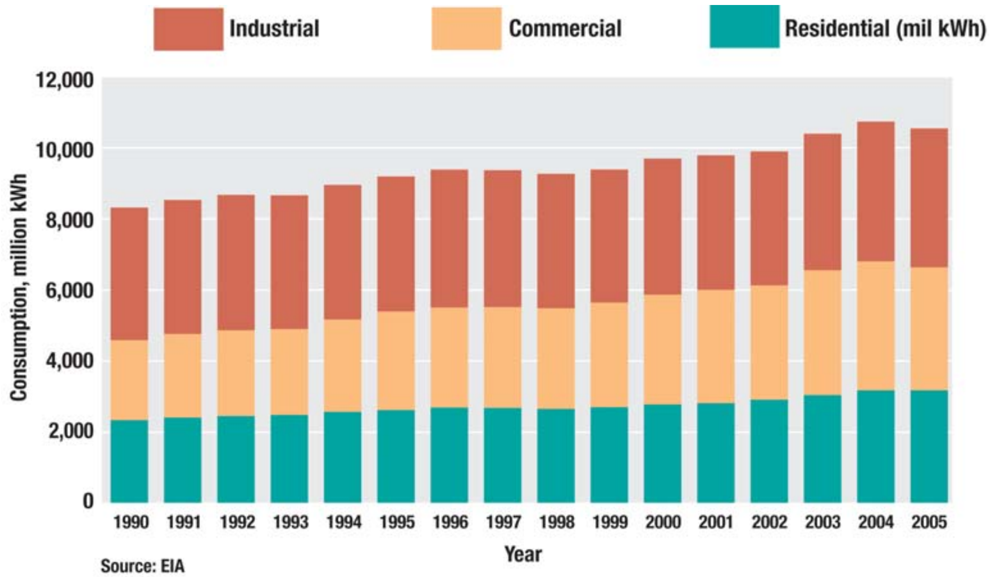

Figure 14. State of Hawaii electricity consumption (1990-2005)

The prices of petroleum products for transportation have experienced increases similar to electricity prices (see Figure 15). For transportation, average daily regular grade gasoline prices have increased by 115% for the State of Hawaii since 2003, increasing from a low of $1.78/gallon in January 2003 to a high of $3.96 in June 2008.

Diesel prices have experienced a similar trend with a 95% increase from $2.02/gallon in January 2003 to $3.95 in March 2008.

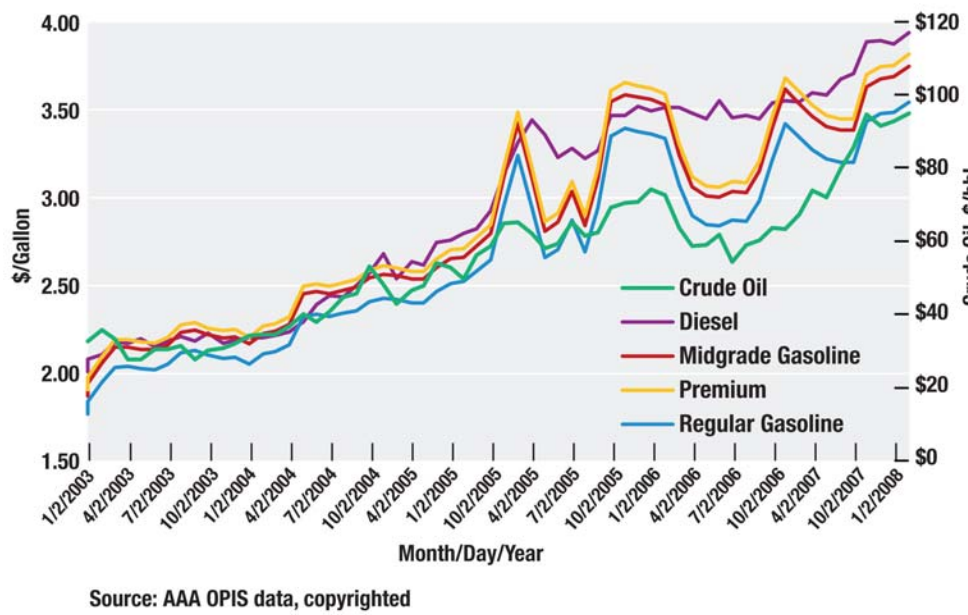

Figure 15. State of Hawaii average daily fuel prices (2003 to present)

Hawaii’s fuel prices are subject to similar factors that impact the rest of the nation (refining capacity, price of crude per barrel, etc.). However, Hawaii’s dependence on imports and geographic isolation suggest that disruption could potentially have larger impacts on pricing factors, due to the limited storage and number of refining facilities.

5. The Technical and Economic Feasibility of Increasing the Contribution of Renewable Energy Resources for Generation of Electricity

5.1 Overview

Renewable energy resources are distinguished by their geospatial and temporal distributions. They vary significantly, not only on the scale of continent or geographic region, but even in different corners of the same acreage or neighboring locations due to microclimate impacts of terrain, wind patterns, shading, precipitation, etc.. Renewable energy resources may also vary by the minute, season, or on geologic timescales. The assessment of renewable energy potential is therefore highly contextual; for the case of Hawaii, it will be considered on an island-by-island basis.

Prospects for increasing the contribution of renewable energy resources to electricity generation throughout the Hawaiian Islands have been reported in a series of studies extending back more than a decade. Renewable energy resources currently contribute approximately 5.5% of Hawaii's energy supply, as summarized in Chapter 3. Island-by-island information on renewable energy supply, with specific focus on electricity generation, is summarized in this chapter (Global Energy Concepts (GEC) 2006). The technical and economic feasibility of increasing the contribution of renewable energy sources for electricity production—wind, photovoltaic (PV), solar thermal, biomass, municipal solid waste/landfill gas,[8] geothermal, hydroelectric, tidal, ocean wave, and ocean thermal—in Hawaii is influenced by available renewable resources, technology and system cost, the past Hawaiian experience with the technology (extensive in several cases), constraints on the use of the land and ocean, and protection of the rich natural beauty and cultural heritage of the Hawaiian Islands.[9]

The technical potential[10] for renewable energy technologies throughout the Hawaiian Islands, as well as factors constraining their siting, are well-represented in numerous data resources, examples of which are shown below. Wind and solar resources have been mapped, although detailed data may not be available yet for a specific site (see Figure 16).[11] Available GIS databases include terrain and land-use information, roads, the existing power and water-processing infrastructure, the location of natural preserves, volcanic rifts, watersheds, and other important information affecting siting.

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[8] Municipal solid waste and landfill gas are not, strictly speaking, renewable energy sources, but do represent more efficient use of resources and are sometimes grouped with renewable resources. They are part of this assessment.

[9] Other technologies, such as tidal and co-produced power from sugar cane ethanol are technical options, but have not been included in this assessment due to limited resource information.

[10] Technical potential is defined as the amount of renewable energy capacity available for development, subject to preliminary screening for viability of siting, energy capture and delivery, and cost. This screening does not assure commercial viability under current policies, regulations, and business practices.

[11] As an example, the NREL/ HNEI team performing the analysis for the report, "Renewable Power Options for Electricity Generation: Molokai Case Study Leading to State-wide Analysis," (Lilienthal et al. 2007), found that while time-averaged 50-meter wind data were available for the location under study, the hourly data needed for more accurate modeling were not available, thereby requiring the use of data from a similar site on another island as a first approximation.

The potential for increased generation from renewable energy technologies for each of the major islands (excluding Niihau and Kahoolawe) is summarized below. The analysis outlines the geographic availability of resources, suitable technologies, siting, and local community openness toward renewable energy options. Technical and economic feasibility limits the amount of renewable energy that can be implemented on each island—the net load, distribution, and grid stability considerations, siting possibilities relative to existing or projected population centers, and the fact that the islands' electrical systems are isolated from each other all are factors in renewable energy development. These factors preclude power sharing without interconnections, which are often not economical. For variable and uncertain renewable energy sources (wind, solar PV and solar thermal, and hydroelectric with its seasonal variation), a significant penetration of Hawaii's grids requires attention to stability, power quality, and energy storage challenges. The effect on overall grid reliability is also a concern. Detailed site-by-site or individual grid-based analyses are required to determine the specifics for each situation, so individual assessments are a necessary exercise and cannot easily be summarized to describe an overall state feasibility scenario.

The technologies discussed in this chapter are sufficiently mature in commercial application and are supported by established industry standards (and other governing laws) related to environmental impact, operations, and safety. Facility configuration issues and siting considerations for these technologies—i.e., required resource, grade of land, land-use compatibility, issues of proximity to infrastructure and other operations, etc.—are also well established. This section focuses on estimating the technical potential for each island using existing studies and other resources. Statewide technical potential and economic impacts of realizing this technical potential are summarized in the Conclusions (see Section 5.8).

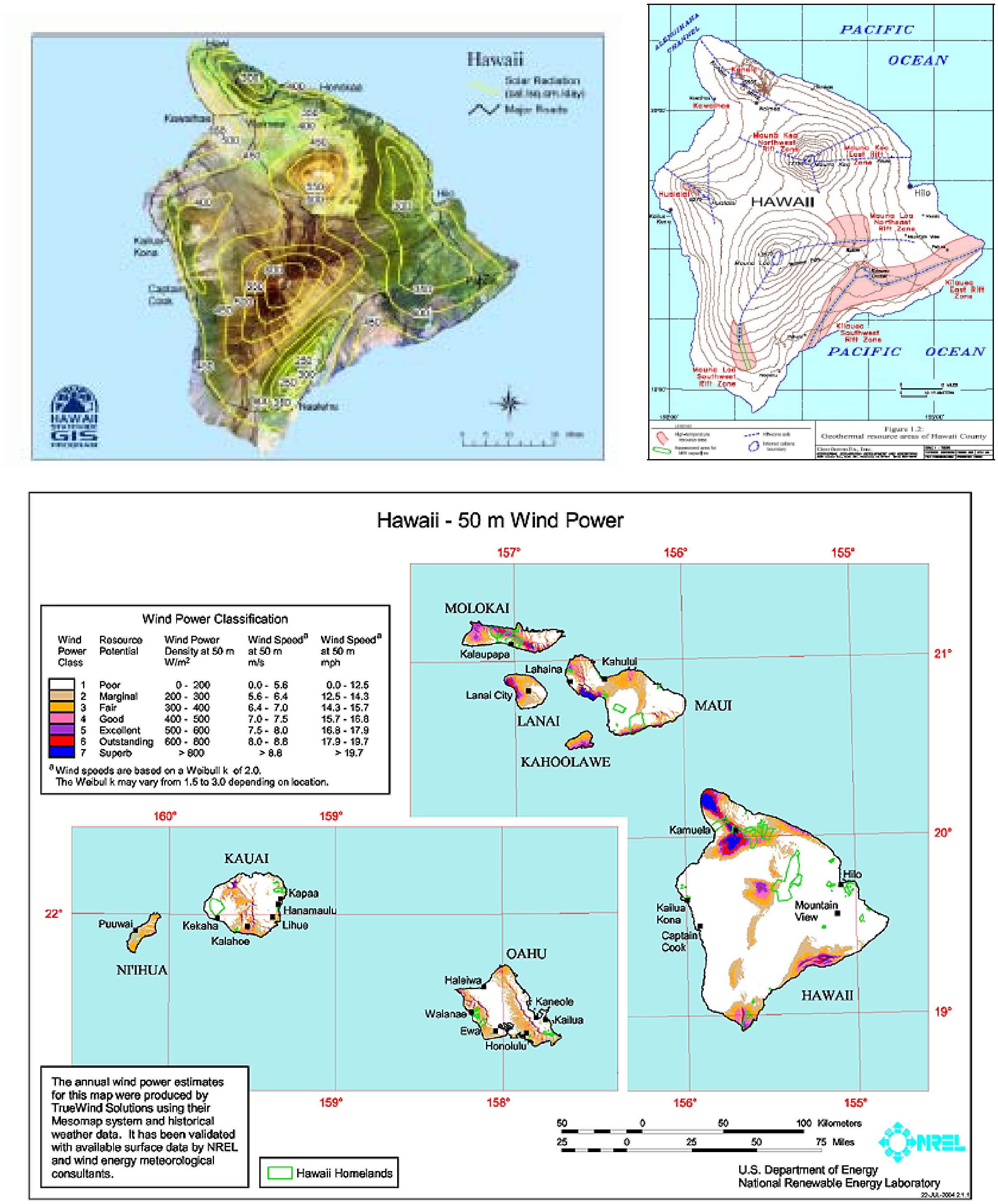
Finally, it is widely known that public sentiment toward a number of renewable energy projects in Hawaii (especially geothermal, hydroelectric, and wind) has historically not been entirely positive due to factors including: communication patterns, limited understanding of local culture and perspectives, the nature of community involvement in project planning, aesthetics, concern about environmental impacts, and competing land-use interests.[12] Any renewable energy project in the Hawaiian Islands should be approached in a way that specifically addresses the concerns and interests of an engaged local population.

5.2 Hawaii

As the largest, youngest, and most volcanically active island, Hawaii has natural potential for almost every form of renewable energy (see Figure 16). Total firm generating capability by the island's utility, Hawaiian Electric Light Company (HELCO), a subsidiary of the Oahu-based

[12] General reference to local opposition to geothermal development on the Big Island, hydroelectric power on Kauai, and wind power on Oahu is made in GEC 2006. As an example, for the specific case of opposition to geothermal energy on Hawaii Island, see Zorpette 1992, Matsuoka et al. 1996, and Chang and Reischmann 2007. These sources reveal a wide range of stakeholders and motivations, and illustrate some of the complexity of the geothermal power undertaking. A full range of opposition and support is indicated, including some variation evidently based on the use to which the geothermal power would be put, and whether the discussion concerns a specific project or more generally long-term sustainability of Hawaiian society and culture.

HECO, is nearly 270 MW (from oil and geothermal sources), with up to nearly 40 MW from variable wind and hydroelectric sources.



Source: GEC 2006

Figure 16. (clockwise from upper left) Solar radiation resource map for the island of Hawaii; geothermal resource for the Island of Hawaii: volcanic rift zones; 50-meter wind resource data for the Hawaiian Islands.

Existing renewables—from geothermal, wind, and hydroelectric sources, and including energy conservation measures—contribute around one-third of electricity sales (HECO 2006). Prospects for additional renewable energy contributions will be addressed by technology beginning with wind power. A summary of new technical renewable energy potential identified for the island of Hawaii, detailed in the following text, is given in Table 5.

Table 5. Summary of Estimated Renewable Energy New Technical Potential for Hawaii Island in MW_e nameplate capacity; existing installed capacity given in brackets

	Wind	Solar	Biomass	Municipal Solid Waste/ Landfill Gas	Geothermal	Hydroelectric	Island Total from All Sources
Hawaii	At least 10 [33]	*(no data)* [0.62[13]]	11	13	750 [30]	20 [15]	804 [79]

5.2.1 Wind

Wind projects on the Big Island began decades ago and are in their second generation, with one new development (Pakini Nui) replacing a previous one (Kamaoa) at the same site (GEC 2006). The best wind resource is at the northern part of the island, in the region between Mauna Kea and Mauna Loa Peaks, and at the island's southern tip—these are the respective sites of the Hawi (10.6 MW), Lalamilo Wells (1.5 MW), and Pakini Nui (21 MW) projects. The northern sites are convenient to the western Kona coast, where significant load growth is projected, and reports indicate technically feasible sites for further development in all three areas, with some transmission system upgrades needed for sufficiently large additional power generation (GEC 2006). Standard environmental considerations include siting the wind turbines away from the paths of migratory birds, and attention near airports to potential radar interference effects.

5.2.2 Solar

Large utility-scale, ground-based photovoltaic (PV) arrays are possible in Hawaii, perhaps especially on the Big Island. Some potential sites for installations, perhaps up to the megawatt level, have been identified: Keahole Point, north Kohala, and Waikoloa (GEC 2006). Rooftop applications, domestic and commercial, may be especially promising, but little current data are available on the number and capacity of existing installations, in part due to the fact that many private rooftop installations are off-grid (DBEDT 2006c and Greer and Boyd 1995). The Island of Hawaii is notable because, in the absence of firm data, it is thought to have more PV —as many as several thousand (HECO 2006)—on private homes per capita than any other location in the United States. There are also some notable examples of commercial applications: on the Big Island, the Mauna Lani resort hotel has installed PV panels producing 620 kW. Rooftop applications offer a siting possibility with significant potential, while satisfying Hawaiian preferences for minimal visual intrusion; no data quantifying this potential for the island were identified. The solar resource tends to be maximum during peak demand times, thus increasing the economic value of the PV contribution.

[13] Additional PV capacity is known to be installed on private rooftops throughout the Hawaiian Islands, but the total capacity is unknown.

Land-use and aesthetic considerations also apply to concentrating solar power (CSP) installations, which may be attractive technically, if executed on a suitably large scale. Also, although not a direct source of electricity *per se*, the electricity-use offsets from solar thermal absorption cooling systems may also be considered. Both of these technologies may find applications on any of the islands, but data estimating the magnitude of their potential in the Hawaiian Islands were not identified during this study.

5.2.3 Biomass

The Island of Hawaii has considerable biomass resources in the form of forest plantings (including a large nonnative species element), macadamia nut shells, municipal solid waste, food waste, fats/oil/grease, and animal manures (Turn et al. 2002). Much of the island's privately held forest lands are intended for timber production, but wastes from milling may provide usable resources. Additionally, some lands previously planted for other purposes (sugar, macadamia nuts) could be planted for energy crops. Nearly 100,000 to 200,000 dry tons of biomass per year has been estimated for identified potential lands (GEC 2006), sufficient to produce approximately 11 MW. (For comparison, a biomass-fueled plant designed for the island of Kauai was to produce 7 MW of power with fuel requirements of approximately 120,000 tons/year.) Biomass plant technology is mature, and the environmental impacts well understood. Assuming transport for the fuel, the plants could be situated near power load centers.

5.2.4 Municipal Solid Waste and Landfill Gas

Municipal solid-waste resources, naturally concentrated in the east (Hilo vicinity) and along the west (Kona) coast, are estimated at up to approximately 200,000 dry tons per year, sufficient to support a cost-effective, waste-to-energy generation plant of as much as 13 MW (GEC 2006). No specific landfill gas resource estimates for the Big Island were identified for this report.

5.2.5 Geothermal

Potential geothermal power generation is significant on the Big Island. Puna Geothermal Venture's 30 MW plant has been operational since 1993; at full operating capacity, it supplies about 20% of the island's electricity. An additional potential for as much as 750 MW of geothermal power has been identified (GEC 2006). This estimate excludes the potential beneath forested lands that have special significance both in Hawaiian culture and island ecology, which have also served as a focus of protest in years past. Any further development of geothermal power would need to be done with great sensitivity to the concerns surrounding the forest reserves.

5.2.6 Hydroelectric

Hydroelectric power provides approximately 15 MW on the Big Island. However, hydropower is considered a variable power source due to seasonal variation of river and stream flows. Potential for an additional 20 MW of hydroelectric generation has been identified for the island of Hawaii (GEC 2006).

5.3 Kauai

Kauai's 2003 total energy requirement was 430 gigawatt-hours or an average power of 49 MW; 94% of this was generated by imported fossil fuel. In January 2006, the standard residential rate was about 29 cents/kWh. Kauai's utility, the Kauai Island Utility Cooperative (KIUC), is the only island utility independent from HECO. KIUC has shown interest in renewable energy, as evidenced by a number of requests for proposals (RFPs) and power purchase agreements; but, to date, no utility-based projects have been completed (GEC 2006). Kauai, interestingly, has a significant history with renewable energy: In the 1980s, nearly half of Kauai's total electricity was generated from renewable (hydroelectric and biomass) sources, a number that decreased greatly as the sugar cane industry that supplied the biomass fuel (bagasse) suffered a significant decline.

The potential for increasing the contributions of renewable power depends on land availability. For possible utility-scale, land-intensive projects, the possibilities are very limited; but Department of Defense (DOD) lands such as Kauai's Barking Sands Pacific Missile Range Facility may provide additional siting alternatives.

KIUC sponsored a Renewable Energy Technology Assessment in 2005 (Black and Veatch 2005). This report identified a mix of recommended wind, hydroelectric, biomass, and municipal solid-waste projects totaling nearly 100 MW.

A summary of new technical renewable energy potential identified for the island of Kauai, detailed in the following text, is given in Table 6.

Table 6. Summary of Estimated Renewable Energy New Technical Potential for Kauai (in MW_e nameplate capacity)

	Wind	Solar	Biomass	Municipal Solid Waste/ Landfill Gas	Geothermal	Hydroelectric	Island Total from All Sources
Kauai	At least 40	285 (utility scale project)	20	8	*n/a*	20	373

5.3.1 Wind

Potential sites for development have been identified near Kalaheo in the south, and Kilauea and Anahola in the northeast. With careful siting and public support, wind farms may be possible in areas of high tourist concentrations, such as Poipu. The 2005 assessment ranked wind power as the most prominent near- and long-term renewable energy option, and 40 MW of potential power were identified at six sites. Grid integration, as noted for the Island of Hawaii, is an important consideration for greater contributions from this technology.

5.3.2 Solar

The 2005 assessment identified significant solar resources on Kauai, with the same siting considerations previously discussed (Black and Veatch 2005). The DOD's Barking Sands Pacific Missile Range facility and the more tourist-intensive Poipu region were particularly identified as sites capable of hosting a 730-acre PV facility. Given current system efficiencies, a facility of that size could alone produce more power than presently used by the entire island.[14] PV is, however, more costly than some other renewable options. Other siting options include distributed systems with siting on commercial and private rooftops. These installations may or may not be connected to the utility grid. No data to quantify the rooftop PV potential for Kauai, as well as solar thermal system potential, were identified.

5.3.3 Biomass

Potential on Kauai to grow crops for energy production has been identified. For example, identified sites (in some cases, on former sugar plantation land) are estimated to be able to produce in excess of 350,000 dry tons per year, which could support as much as 20 MW of power, approximately (GEC 2006).

5.3.4 Municipal Solid Waste and Landfill Gas

Municipal solid waste was also identified as a source of interest, sufficient to power a plant providing perhaps 7 MW of electricity (Black and Veatch 2005). One estimate for a potential landfill gas development near Kekaha suggests a capacity of up to a megawatt of electricity (GEC 2006).

5.3.5 Geothermal

There is no significant geothermal resource on Kauai.

5.3.6 Hydroelectric

Nearly 20 MW of hydroelectric potential has been identified around the island; previous hydroelectric development efforts have received considerable public protest.

5.4 Lanai

Lanai, part of Maui County, is serviced by the Maui Electric Company (MECO). There is presently 9.4 MW of oil-based generating capability on the island (HECO 2005). A summary of new technical renewable energy potential identified for the island of Lanai, detailed in the following text, is given in Table 7.

Table 7. Summary of Estimated Renewable Energy New Technical Potential for Lanai (in MW_e nameplate capacity)

	Wind	Solar	Biomass	Municipal Solid Waste/ Landfill Gas	Geothermal	Hydroelectric	Island Total from All Sources
Lanai	up to 400	1.5	*(no data)*	*n/a*	*n/a*	*n/a*	401.5

5.4.1 Wind

The wind resource for Lanai appears best on the southwest part of the island, where one potential site has been identified (GEC 2006). However, there are no transmission lines near the site, and

[14] This analysis assumed a 285 MW installation with a 20% capacity factor (Black and Veatch 2005).

population growth is projected to occur on the other side of the island. Castle & Cook, Inc. is considering a wind farm that could generate up to 400 MW of power, most of which might be sent by undersea cable to Oahu (National Windwatch 2007).

5.4.2 Solar

Manele Bay on the southern coast of the island, an area of resort and home development, is identified as having potential for a utility-scale PV project (GEC 2006), and a planned 1.5 MW PV installation was recently announced (Hill 2007). Transmission capability on the island is limited, but the proposed installation would be located about 1.5 miles from the existing central power plant. Lower population density may make rooftop PV applications, including off-grid, an attractive option, but no data to quantify this potential for Lanai were identified. No data quantifying solar thermal system potential were identified.

5.4.3 Biomass

Biomass-based energy production on Lanai is assessed as non-promising (GEC 2006).

5.4.4 Municipal Solid Waste and Landfill Gas

The amount of municipal solid-waste generation by Lanai's small population is estimated to be insufficient to support a cost-effective waste-to-energy plant (GEC 2006).

5.4.5 Geothermal

There is no significant geothermal resource on Lanai.

5.4.6 Hydroelectric

No significant hydroelectric resource has been identified for Lanai.

5.5 Maui

Maui Electric Company operates oil plants providing about 250 MW of baseload electric power. Another approximate 16 MW of baseload power is produced by the Hawaiian Commercial and Sugar Company in a biomass plant primarily using bagasse (plant fiber), but augmented by fossil fuel to meet the generation commitment. About 20% of MECO's sales are from renewable energy, produced by energy conservation as well as Maui-based wind, biomass, and several megawatts of hydroelectric power (HECO 2006). As indicated below, there are significant untapped renewable energy resources on Maui.

A summary of new technical renewable energy potential identified for the island of Maui, detailed in the following text, is given in Table 8.

Table 8. Summary of Estimated Renewable Energy New Technical Potential for Maui (in MW_e nameplate capacity - existing installed capacity given in brackets [X])

	Wind	Solar	Biomass	Municipal Solid Waste/ Landfill Gas	Geothermal	Hydroelectric	Island Total from All Sources
Maui	At least 40 [30]	*(no data)*	8 [up to 16]	*(no data)*	140	3	191 [46]

5.5.1 Wind

Maui hosts the biggest wind farm in Hawaii, the 30 MW Kaheawa Pastures project. Another 40 MW project, possibly with a pumped hydroelectric storage capability, has been proposed for the Ulupalakua Ranch, which is in an area of southwest Haleakala that has additional potential. Other development sites may include the northwest slope of Haleakala near the Kaheawa Pastures project; Puunene, the old Maui airport site; and on the slope of the West Maui Mountains within sight of tourist developments (GEC 2006).

5.5.2 Solar

Proposed sites for utility-scale generation include the Kahalui airport, near the Kahalui power plant; Kiihei, an area with anticipated load growth; and Puunene, as noted in the previous section. Rooftop siting on commercial and private structures may also be a reasonable option, given the scarcity of land. No data to quantify the potential for rooftop PV or solar thermal generation for Maui were identified.

5.5.3 Biomass

Identified lands, on former or present plantations, are estimated to be capable of growing in excess of 150,000 tons/year (as much as 582,000 tons/year) dry weight of tree or grass crops, equivalent to approximately 8.5 MW (as much as 33 MW) generating capacity (GEC 2006).

5.5.4 Municipal Solid Waste and Landfill Gas

Quantitative estimates for Maui’s municipal solid-waste production and landfill-gas potential were not identified for this report.

5.5.5 Geothermal

Maui is the only other island besides Hawaii with significant geothermal electricity-generating potential. Identified undeveloped resources are in two zones southwest and east of Haleakala, with potential estimated at 140 MW (GEC 2006).

5.5.6 Hydroelectric

A potential site for a 3 MW hydroelectric plant has been identified at Wailua Iki; in the past, there has been significant public opinion against this development (GEC 2006).

5.6 Molokai

Molokai is also part of Maui County and is serviced by MECO, which has approximately 12 MW (HECO 2006) of oil-based diesel electricity generation capability. A summary of new technical renewable energy potential identified for the island of Molokai, detailed in the following text, is given in Table 9.

Table 9. Summary of Estimated Renewable Energy New Technical Potential for Molokai (in MW_e nameplate capacity)

	Wind	Solar	Biomass	Municipal Solid Waste/ Landfill Gas	Geothermal	Hydroelectric	Island Total from All Sources
Molokai	up to 300	*(no data)*	6	*n/a*	*n/a*	*n/a*	306

5.6.1 Wind

Molokai experimented with wind power coupled to a diesel generator in the early 1990s, but the equipment is no longer operating. Old wind data show a good resource on Ilio Point, the northwest tip of the island, but there is no infrastructure for transmission to the nearest load center (about 10 miles away).

Preliminary analysis of Molokai (Lilienthal et al. 2007) indicates that perhaps 50% of power generation (6 MW) could be met cost-effectively with four 1.5 MW wind turbines. A more detailed summary of the preliminary assessment is in Appendix A. Using data provided by MECO, initial analysis indicated that increasing levels of wind power could be cost-effective. It is estimated that diesel fuel use could be reduced by a range of 38% to 70% with overall life-cycle cost savings between 20% and 40%.[15] A private company has expressed interest in building a wind farm producing up to 300 MW, most of which would be intended for transmission to Oahu by undersea cable (Molokai Times 2007).

5.6.2 Solar

West Molokai is identified as having a suitable solar resource for PV development. No data to quantify the potential for rooftop PV and solar thermal electrical generation were identified.

5.6.3 Biomass

The Palaau area is estimated to have the potential to produce about 100,000 dry tons per year of grasses, enough to fuel a biomass plant of about 6 MW.

5.6.4 Municipal Solid Waste and Landfill Gas

Molokai’s municipal solid waste production is estimated to be too low to support a waste-to-energy plant (GEC 2006).

[15] The analysis for Molokai also highlighted some areas requiring additional analysis. Grid stability issues associated with wind variability and intermittency would require study. While economically feasible, significantly increased amounts of wind generation would depend on how the utility handles integration issues, such as spinning reserves, advanced generation controls, and operations and maintenance issues associated with running diesel generators at lower load levels.

5.6.5 Geothermal

There is no significant geothermal resource on Molokai.

5.6.6 Hydroelectric

No significant hydroelectric resource has been identified for Molokai.

5.7 Oahu

Oahu is serviced by HECO, operating 1,722 MW of oil-based electricity generation. About 10% of Oahu's sales are from renewable energy in the form of energy conservation and biomass generation (solid municipal waste) (HECO 2006). The past history of renewable energy projects on Oahu suggests a great need for aesthetic and cultural awareness, with particular attention to siting that might impact views for tourists.

A summary of new technical renewable energy potential identified for the island of Oahu, detailed in the following text, is given in Table 10.

Table 10. Summary of Estimated Renewable Energy New Technical Potential for Oahu (in MW_e nameplate capacity - existing installed capacity given in brackets [X])

	Wind	Solar	Biomass	Municipal Solid Waste/ Landfill Gas	Geothermal	Hydroelectric	Island Total from All Sources
Oahu	At least 50	*(no data)*	7	*(no data)* [45]	*n/a*	*n/a*	57 [45]

5.7.1 Wind

A 12 MW wind farm was operated at Kahuku, finally closing in 1996. Because of public opinion against wind developments at other proposed sites, Kahuku, now owned by the U.S. Army, may be the most promising site on Oahu for a significant wind development similar to the old project. Technically, the potential on identified sites is at least 50 MW, of which 40 MW would be in the protested Kahe area (GEC 2006).

5.7.2 Solar

The land required for utility-scale PV projects is especially scarce on Oahu. Some potential sites have been identified, including former sugar fields north of Ewa, land adjacent to the former Barber's Point Naval Air Station, the site of the Naval Communications Center and Ammunition Storage facility at Lualualei, and the west loch of Pearl Harbor. Commercial and private rooftop PV installations may be a more attractive approach on Oahu than utility-scale projects. No quantitative assessments of the rooftop PV potential for Oahu were identified. Data quantifying the potential for solar thermal generation also were not identified.

5.7.3 Biomass

Former sugar plantation land near Waialua on Oahu's north coast is estimated to be capable of producing 128,000 dry tons/year of grass crop, which could support nearly 7MW of electricity generation (GEC 2006).

5.7.4 Municipal Solid Waste and Landfill Gas

An operating plant capable of processing 777,600 tons per year of municipal solid waste already produces more than 45 MW of electricity (HECO 2006). No assessment of the potential increase of waste-to-energy production on Oahu was identified.

5.7.5 Geothermal

There is no significant geothermal resource on Oahu.

5.7.6 Hydroelectric

No significant hydroelectric resource was identified for Oahu.

5.8 Conclusions

Technical potential (exclusive of economic considerations): It appears to be technically feasible to significantly increase the contribution of renewable energy resources to electricity generation for Hawaii, subject to such identified constraints as site selection; residents' environmental, aesthetic, and cultural sensitivities; and the vision of each island for the objective optimal mix of renewable sources with fossil fuel-based generation. Of course, all of these constraints should be considered given future prospects for (and net costs of) continued fossil fuel use. The technologies discussed in this section are commercially available today—in most cases, already cost-competitive with existing generation in Hawaii, as reported below. Table 11 summarizes the estimated renewable energy potential, with existing installed capacity given for comparison. Note that the 287 MW_e solar potential represents ground-mounted utility-scale opportunities that might be satisfied by either solar photovoltaic or solar thermal technologies. An estimate of rooftop solar potential (see footnote 14) leads to a second, larger estimate of net solar potential of more than 2,000 MW nameplate capacity.

This review of existing studies, augmented by select additional analysis, indicates that Hawaii may have at least 2,000-4,000 MW nameplate capacity of untapped renewable energy resources available for development, subject to technical considerations that include location of resources relative to electricity demand (a major challenge for Oahu, location of highest load and lowest identified renewable resource potential), grid integration and stability, power quality, and the characteristics of power storage options available for specific developments. For general sense of scale, the current installed electric generating capacity in Hawaii is 2,414 MW_e, 83% of which is fuel-oil generated.

Movement toward realizing the identified potential will require detailed attention to the integration of time-varying power outputs—such as those provided by wind, solar, and seasonally varying hydroelectric generation—into the existing grid. In some cases, existing transmission systems would need to be augmented to accommodate substantial inputs from renewable sources. Also, fundamental questions of land use will need to be resolved, as one example, concerning the optimal balance between electricity generation, fuel source production, and food production in the case of biomass opportunities. The small scale of most individual island power grids and lack of interconnection among the islands pose unique technical and commercial challenges for significant use of renewable power sources. These factors will require careful attention to stability, power quality, and energy storage challenges, as well as island-by-island and interisland grid reliability. Further, in addition to the solution of technical issues, tapping this potential will require supportive legislative, regulatory and utility actions.

The estimated potential compares with HECO's proposal for 560 MW of various types of renewable energy for the islands in its service area,[16] and the KIUC study proposal for projects yielding 90 MW of renewable power just for the island of Kauai (Black and Veatch 2005). The total potential is likely even greater, because local resource assessments and project-specific technical and economic analyses were not uniformly available for all the potential sites identified for this assessment—and also because this estimate focused on a set of technologies widely accepted as mature.

An independent community support assessment was recently conducted for the Hawaii 2050 Sustainability Task Force (Chang and Reischman 2007). Energy was identified as a theme in 29 write-in comments. Most of the comments envisioned more renewable energy uses, including solar and wind. Geothermal and nuclear power were also noted. Reduced reliance on fossil fuels and increased local production of biofuel was noted in several comments. There also were several comments about creating incentives, such as tax credits, for using cleaner or renewable energy sources.

"Increase use of alternative and renewable energy; achieve greater energy self-sufficiency" was the second highest priority based on community meeting discussions. This followed "Improve environmental protection and preservation; achieve enlightened stewardship of natural resources (land, water, species and air)." Several strategies were identified, none of which specifically addressed increased use (or importation of) natural gas (which will be discussed in the next section).

[16] See http://www.hawaiisenergyfuture.com. The breakdown, which in updated form online totals 560 MW, includes: 100 MW windpower, 80 MW pumped storage hydroelectric, 110 MW biofuel in new plants, 83 MW biofuel or biodiesel in existing plants, 85 MW solar, 40 MW garbage to energy, 30 MW geothermal, 25 MW biomass, and 7 MW landfill gas. This list reflects HECO's thinking about practical projects, and is not presented as a summary of technical potential.

Table 11. Summary of Estimated Technical Potential for New Hawaiian Renewable Energy Excluding Economic Considerations (in MW_e nameplate capacity - existing installed capacity given in brackets [X])

	Wind	Solar	Biomass	Municipal Solid Waste/ Landfill Gas	Geothermal	Hydroelectric	Island Total from All Sources
Hawaii	At least 10 [33]	*no data* [0.62[17]]	11	13	750 [30]	20 [15]	804 [79]
Kauai	At least 40	285 (utility scale project)	20	8	*n/a*	20	373
Lanai	Up to 400	1.5	*no data*	*n/a*	*n/a*	*n/a*	402
Maui	At least 40 [30]	*no data*	8 [up to 16]	*no data*	140	3	191 [46]
Molokai	Up to 300	*no data*	6	*n/a*	*n/a*	*n/a*	306
Oahu	At least 50	*no data*	7	*no data* [45]	*n/a*	*n/a*	57 [45]
TOTALS	840[18] [63]	287 (2,287 [19]) [0.62]	52 [16]	21 [45]	890 [30]	43 [15]	2,133 (4,133[20]) [~170]
NET NEW POTENTIAL FROM ALL SOURCES: ~ 2133 MW_e (~4,133 MW_e); NET INSTALLED ~170 MW_e							

Economic Considerations. The economics of the various renewable energy technologies must be addressed on a project-by-project basis. Real-time evaluation of the costs of both utility-provided power and the candidate's renewable power sources, as they are expected to perform in a specific location, must be compared. However, the relative cost-effectiveness of renewable energy may be examined by comparing averaged electricity costs for the various Hawaiian utilities with typical cost ranges for electricity from renewable energy sources.

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[17] Additional PV capacity is known to be installed on private rooftops throughout the Hawaiian Islands, but the total capacity is unknown.

[18] A statewide Hawaiian wind potential of 1,850 MW_e was identified in an analysis performed by NREL in response to the Hawaii EPAct Section 355 tasking. High-resolution wind mapping was used, as well as land-exclusion filters based on environmental, land-use, and other territorial characteristics. This estimate reflects class 5 and better wind resource, and it is noted here to give a sense of net developable wind potential not reflected in the 840 MW_e of specifically identified potential projects (Elliott 2006).

[19] In the previously noted absence of data for island-by-island PV rooftop potential, an estimate of 2,000 MW_e domestic and commercial rooftop PV potential for the state of Hawaii was taken from Paidipati et al. 2008. Added to the 287 MW_e identified in the text, the solar PV total becomes 2,287 MW_e. Note that no data quantifying potential contributions from solar thermal electrical generation were identified, but the 287 MW_e of identified utility-scale potential could likely be realized with either PV or solar thermal technology.

[20] This total includes the upper-bound solar potential.

The cost of utility-provided power in Hawaii—given the present level of oil reliance—follows the global oil market; existing market dynamics do not provide clear guidance for reasonable projections of future oil prices. Therefore, the following averaged electricity prices, based on 2006 data from the Energy Information Administration, may be considered as a baseline: 17.7¢/kWh for HECO (Oahu), 27.2¢/kWh for MECO (Maui, Molokai, and Lanai), 29.5¢/kWh for HELCO (Hawaii Island), and 32.3¢/kWh for KIUC (Kauai).[21] These costs may be compared with typical price ranges for electricity from renewable sources—without incentives,[22] and not accounting for additional project-specific transmission infrastructure. By technology, representative cost ranges of electricity over recent years are:[23]

- 5-8 ¢/kWh for wind,[24]
- 20-40 ¢/kWh for solar (PV),[25]
- 12-18 ¢/kWh for concentrating solar power,[26]
- 4.5-17 ¢/kWh for biomass,[27]
- 3-12 ¢/kWh for municipal solid waste/landfill gas,[28]
- 4-7 ¢/kWh for geothermal,[29] and
- 4-7 ¢/kWh for hydroelectric.

While the cost, and cost-effectiveness, of these technologies will vary by island and by site, and depend upon the degree to which energy delivery infrastructure requires accommodating changes, these ranges generally compare favorably with the present utility electricity costs cited above, and support the overall economic viability of renewable energy in Hawaii.

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[21] Data from Energy Information Administration's Form EIA-861 for 2006, the latest date for which data were available as of this writing. See http://www.eia.doe.gov/cneaf/electricity/page/eia861.html.

[22] Current federal tax incentives, together with the state of Hawaii's personal and corporate energy tax credits (35% of installed cost for solar thermal and photovoltaic systems, 20% for wind, both with ceilings) can affect the economic viability of the subject renewable energy technologies. Further information is on the DSIRE USA Web site. For federal incentives, see http://www.dsireusa.org/library/includes/genericfederal.cfm?CurrentPageID=1&state=us&ee=1&re=1. For state of Hawaii incentives, see http://www.dsireusa.org/library/includes/incentive2.cfm?Incentive_Code=HI01F&state=HI&CurrentPageID=1&RE=1&EE=1

[23] A primary source for these cost ranges is Martinot et al. 2007, commissioned by the Renewable Energy Policy Network for the 21st Century, produced in collaboration with the Worldwatch Institute and a global network of research partners. Data sources cited in this document include the National Renewable Energy Laboratory, World Bank, and International Energy Agency and its Implementing Agreements. The reference notes that "Many current estimates are unpublished. No single published source provides a comprehensive or authoritative view on all costs." Additional references for specific cost estimates are given in footnotes for individual technologies.

[24] On-shore siting, 1-3 MW, 60-100 meter blade diameter. See also Wiser and Bolinger 2007.

[25] For low-latitude locations, assuming solar insolation of 2500 kW-h/m^2/yr

[26] For a 50-500 MW parabolic trough and 10-20 MW tower designs

[27] This range brackets estimated costs for a number of biomass technologies, including a 25 MW fluidized bed, 25 MW stoker, 25 MW integrated gasification combined cycle, and a 1 MW wastewater treatment plant. See V. Tiangco et al. 2005. Some figures were given in 2010 dollars, but are accommodated within the broad cost range cited. This range is also consistent with that given for biomass systems in the Renewables 2007 Global Status Report *op. cit.*

[28] For a 12 MW system (Advanced Energy Strategies 2004). A 1 MW landfill gas system is costed at ~3.7¢/kWh (2010 dollars) in Tiangco et al. 2005.

[29] 1-100 MW binary, single- and double-flash, natural steam systems. From Martinot et al. (2007)

Negotiated prices for renewable electricity in Hawaii, as in each state, are subject to specific considerations of state regulation, utility planning, contract structures, and rate case rulings by public utility commissions (for regulated utilities). It should also be noted that the State of Hawaii Administrative Rules Title 6 provides for "…increases or decreases…in rates reflecting increase or decrease…in cost incurred by electric or gas utilities for fuel and purchased energy due to changes in the unit cost of fuel and purchased energy" (State of Hawaii 2008). This rule has been interpreted to allow the pricing of renewably generated electricity contracts to be tied to cost avoidance based on standard oil-based electricity generation, and indexed to the future price of oil.

Finally, there is the question of broader economic impacts of directly offsetting fossil fuel power generation by increased renewable power generation. A preliminary case-study analysis (see Appendix A), suggests that using current production costs, increased use of renewable energy could result in overall lower life-cycle cost to the utility and consumers; however, a detailed economy-wide impact analysis has not been completed. Further detailed analysis, including engineering reliability studies, and statewide fossil fuel demand reduction for defined increased renewable power generation portfolios are needed to evaluate the statewide economic impacts.

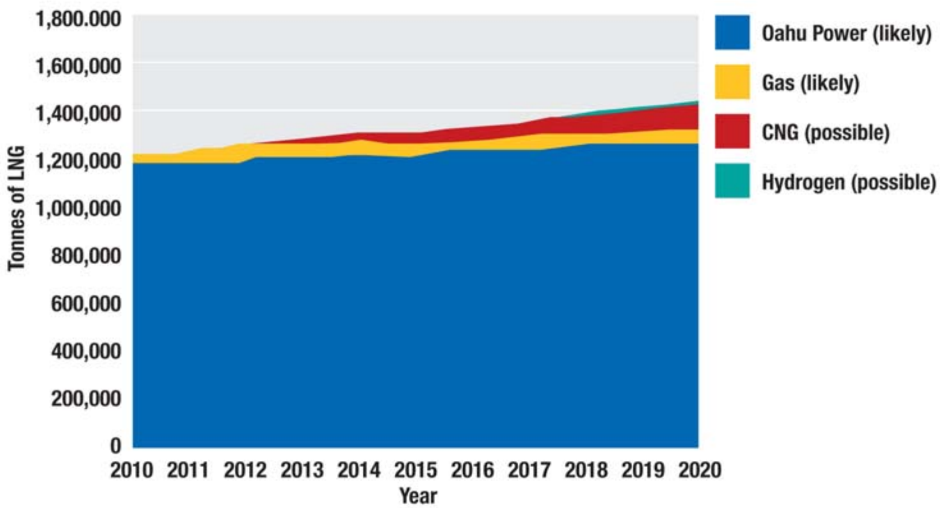
6. The Technical and Economic Feasibility of Using Liquefied Natural Gas to Displace Residual Fuel Oil for Electric Generation

An assessment titled “Evaluating Natural Gas Import Options for the State of Hawaii,” was conducted by FACTS Global Research.

The assessment evaluated a number of possible demand scenarios for LNG for the state. Before proceeding with a more detailed examination of the challenges of bringing LNG to Hawaii, as presented in the following sections, it should be pointed out that LNG would likely be delivered to Hawaii under one of three scenarios: (1) A supplier in Asia, or even Latin America, would deliver LNG cargoes from a single supply source that are solely destined for Hawaii (this is the traditional model); (2) A supplier in Asia/Latin America would deliver LNG cargoes from multiple supply sources to Hawaii (this is the new trend, as it optimizes shipping); or (3) A supplier from Asia would deliver to the U.S. west coast and drop off some cargo along the way or as backhaul. According to the assessment, each of these scenarios is plausible. However, 1 and 2 are viewed as the most likely scenarios.

As shown in Figure 17, for a scenario where multiple supply sources are used (scenario 2), electricity generation was found to likely dominate LNG use under the scenario assumptions. According to the study’s estimates, if all of the major oil-fired power plants on Oahu were to be converted to gas, Hawaii would require approximately 1.40 million tonnes (mt) of LNG in 2013 (a hypothetical date for first imports) for use in power generation. This would grow to 1.48 mt by 2020.

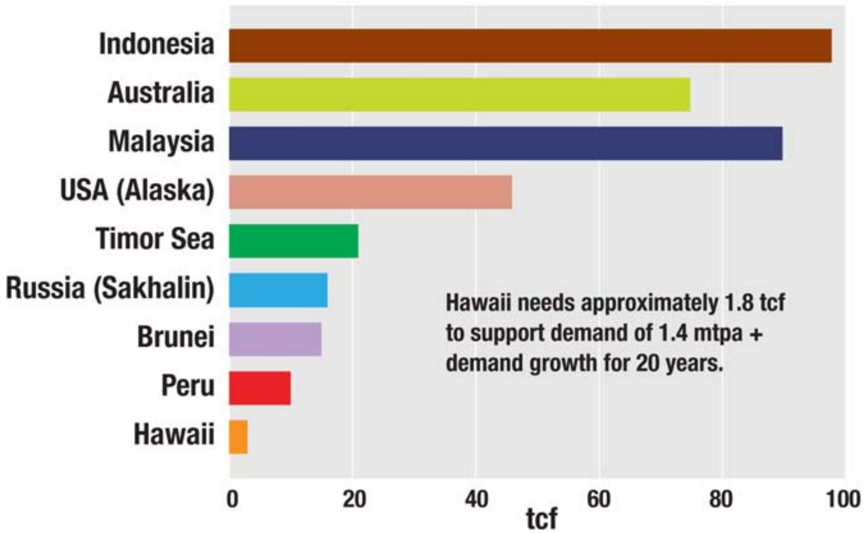
In comparison to consumption in the power sector, the Oahu utility gas market was estimated to require only 0.067 mt in 2013. Other possible uses were evaluated, including Compressed Natural Gas (CNG) for vehicles, neighbor island use, and reforming natural gas into hydrogen for fuel cells.



Source: Calculations based on information provided by DBEDT

Figure 17. Forecast LNG demand in Hawaii in the period 2010 to 2020

The possible demand scenarios evaluated require approximately 1.8 trillion cubic feet over the life of a 20-year contract. On a regional basis, as shown in Figure 18, Hawaii's reserve requirements would be relatively small when compared to the proven reserves of major potential suppliers.



Source: BP Statistics

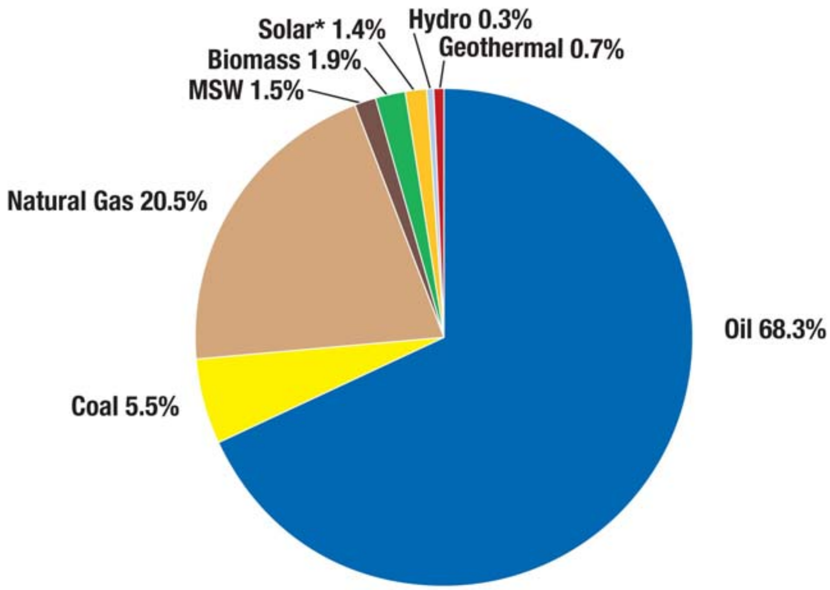
Figure 18. Proven gas reserves for selected countries compared to Hawaii's need (as of January 1, 2007)

CNG technology offers an alternative to transporting natural gas instead of using pipelines and LNG. Unlike LNG, where the main costs are in the liquefaction process, the actual transportation of CNG is capital-intensive and accounts for about 85% of the total capital costs, with the remaining 15% being split between compression and loading at the point of origin and unloading at the final destination. Due to the high costs of the ships, CNG works best in regional markets (i.e., where the buyer and seller are within 2,500 miles or less). Alaska could be a prime candidate for supplying CNG to Hawaii, based on technical and economic considerations.

While no commercial large-scale trade currently exists in CNG, the technology is well known and has substantially fewer requirements for facilities and infrastructure compared to LNG. It has a lower cost of production and storage compared to LNG, because it does not require an extensive cooling process and cryogenic tanks. Moreover, CNG is geared to satisfying small demand markets and monetizing smaller-scale gas reserves.

Transporting CNG to neighbor islands would likely be more attractive than delivering LNG, due to the substantially lower infrastructure costs. In addition, if natural gas were to be delivered in the form of CNG into the state, a larger percentage of the transport market might be captured compared to LNG imports, because there would be no added costs of converting LNG into CNG.

The assessment concluded that there are a number of possible advantages to pursuing natural gas imports into Hawaii. As shown in Figure 19, natural gas offers the opportunity for substantial diversification away from oil within a decade. If Hawaii chooses to pursue gas imports, it could reduce oil's share of the primary energy mix by approximately 20% within four to seven years of moving forward. Natural gas may be obtained from a variety of supply sources, including Australia or domestic sources such as Alaska. The electric utilities could retain the ability to consume fuel oil in the event of an LNG supply disruption, further enhancing energy source diversity.



***Solar includes wind and solar-heated water**
Source: DBEDT, preliminary data for 2004

Figure 19. Potential State of Hawaii primary energy fuel mix under an imported Natural Gas Scenario

Among the main disadvantages of Hawaii as an LNG market is that it is a relatively small market with limited growth potential, and it may be both expensive and difficult to establish a receiving terminal. Figure 20 illustrates the range of potential costs to supply LNG to Hawaii versus other fuels. The latest LNG prices agreed on in 2006/07 are included with the assumption of delivery to Hawaii. In addition, there is the inclusion of a vision of future prices in the Asia-Pacific region and a forecast of the electric utilities' low-sulfur fuel oil (LSFO) and diesel costs through 2020[30].

Prices shown include estimated shipping costs from two supply sources to Hawaii, in addition to the estimated cost of $0.53-0.79/MMBtu for onshore regasification, port costs, and other capital costs.[31] The delivered ex-ship LNG price is in the range of $9.20-$12.40/MMBtu, with an average price of $10.80/MMBtu.

[30] Forecasts provided by the FACTS, Inc, report, "Evaluating Natural Gas Options for the State of Hawaii."
[31] The free on board (FOB) prices for the Australian and Qatari deals were approximately $7.10/MMBtu and $9.20/MMBtu, respectively.

Figure 20 shows that LNG prices to Hawaii can compete with the electric utilities' LSFO and diesel costs if the receiving terminal is built onshore.[32]

The levelized cost of electricity for natural gas generation would range from 9-11¢/kWh based on the LNG pricing of $9.20-$12.40/MMBtu, and assuming $780/kW capital costs, a heat rate of 6870 Btu/kWh, and an 80% capacity factor. The generation costs of many of the renewable power sources compare favorably to natural gas under this scenario.

With respect to the CNG offshore terminal, a transport tariff of $4/MMBtu from an Alaskan supply source was estimated, which accounts for the capital costs of all the ships, the transport of the gas from the point of origin to the final destination, and the construction and operation of the offshore storage facility. To compete with future LSFO costs, the FOB price of Alaskan gas would have to be about $5-6/MMBtu.

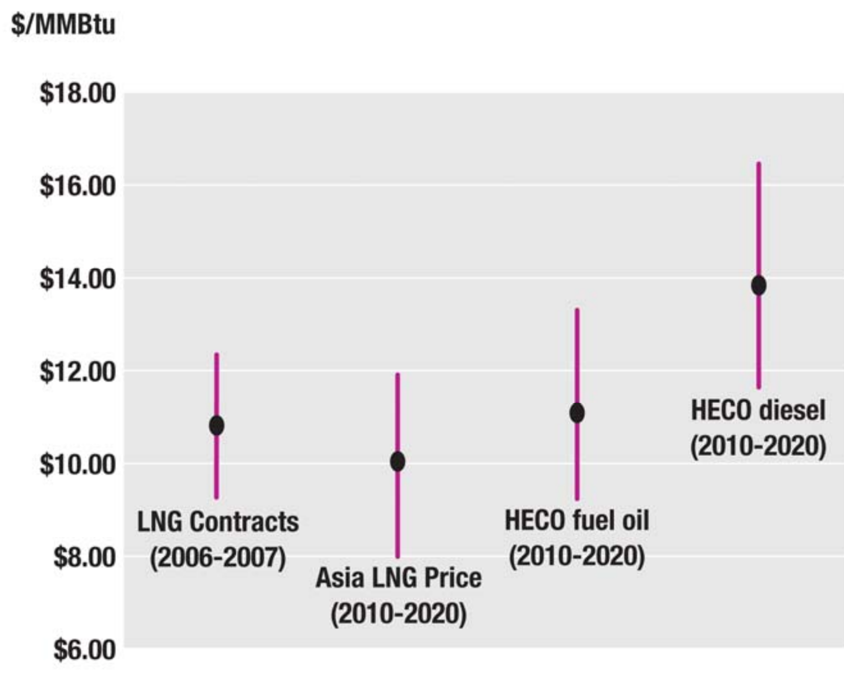


Figure 20. Future cost in Hawaii of LNG vs. other fuels (high/low and average)

6.1 Economic Impact of the Introduction of Natural Gas to Hawaii

Assessments indicated that if Hawaii were able to secure an LNG contract that was capped at a delivered price of about $9-10/MMBtu, the fuel savings to consumers would be tens of millions of dollars per year because the price of gas to the power plants would be, on average, about $1-

[32] If an average of $2/MMBtu for shipping and onshore regasification costs to Hawaii is added, the delivered ex-ship (DES) LNG price would be in the range of $8-$12/MMBtu, with an average price of $10/MMBtu. The forecasted electric-utility LSFO and diesel costs are predicted to average approximately $11 and $14/MMBtu (2007 dollars), respectively, from 2010-2020.

2/MMBtu less than the price forecast for LSFO. Additional savings would be realized in the transport sector, with the retail price for gasoline currently about $24/MMBtu, using a per-Btu basis for comparison. An economic impact analysis on the refinery and overall state economy was not conducted. The cap on the delivered price for these contracts would be important as natural gas prices have been historically volatile and are expected to remain so.

6.2 Conclusions

There appear to be both benefits and challenges when considering natural gas for Hawaii's energy needs. Advantages include near-term displacement of imported oil, potential for CNG in transportation applications, and potential cost savings to consumers. However, major challenges remain regarding Hawaii's limited size as a market for LNG and its constrained potential for growth. Additionally, natural gas prices tend to be volatile, so reliable pricing would be dependent on firm contracts for a delivered product. Natural gas as an energy resource would also mirror some of the uncertainty of oil dependence in terms of reliance on importation and the potential for supply disruption. Continued fuel oil availability for the electricity sector would dampen the severity of these effects. The possibility of shorter-term displacement of oil is significant, but the benefit should be weighed carefully with mitigating factors.

7. The Technical and Economic Feasibility of Using Renewable Energy Sources (Including Hydrogen) for Ground, Marine, and Air Transportation Energy Applications to Displace the Use of Refined Petroleum Products

7.1 Bioethanol

An assessment report titled "Accelerated Use of Renewable Resources for Transportation Fuels" was prepared.[33] The assessment evaluated multiple feedstocks and production pathways on an island-by-island basis. The scope of the analysis explored the potential for producing ethanol in Hawaii from indigenous feedstocks.[34] Previously published studies show consistent results (BBI International Consulting 2003, DBEDT 2006b, Stillwater Associates 2003, University of Hawaii 1999). The summary of statewide potential for bio-ethanol production is summarized in Table 13.[35] The evaluation indicated that using all of the Natural Resource Conservation Service Zoned Agricultural (NRCS-SS-ZA) lands had the potential to produce enough ethanol to completely displace current gasoline use statewide at the time of the assessment. Four crop scenarios were investigated: 1) sugar cane grown on all soils suitable for sugar, 2) leucaena and eucalyptus grown on all soils suitable for trees, 3) sugar cane given first priority, grown on all soils suitable for sugar; and leucaena and eucalyptus given second priority, grown on remaining soils suitable for trees, and 4) banagrass grown on all soils suitable for sugar. The third crop scenario produced the most ethanol for each of the land subgroups with a maximum value slightly greater than 700 million gallons of ethanol per year. For comparison, the total motor gasoline sales in Hawaii in 2005 totaled 454 million gallons or 668 million gallons of ethanol on an energy-equivalent basis.

[33] http://hawaii.gov/dbedt/info/energy/publications/Renewble_Fuel_Assessment.pdf.
[34] Given the scope of this report, it should be noted that the assessment was accomplished at a level that did not address many of the implementation issues that will be critical to such an endeavor: water availability and cost, land availability, land use priorities, impacts on environmental quality, economic impacts, and costs of production for ethanol conversion technologies that are currently in the development stage. Each of these issues merits additional study, whether for guiding future government policy making or investing in ethanol production ventures.
[35] The assessment cautions, however, that many of the implementation issues that would be critical to large-scale ethanol production (such as those listed in footnote 35) were not addressed.

Table 12. Summary Table of Statewide Ethanol Potential for Four Land Groupings and Four Crop Scenarios in Hawaii[36]

	Total Potential, Zoned Ag	Zoned Ag, State Owned	Zoned Ag, Large Land Owners	Zoned Ag, ALISH[37]
1) **Sugar cane**				
Acres	360,324	50,828	252,145	329,520
Ethanol (mil gal/yr)	429	61	312	393
2) **Trees**				
Acres	698,632	160,360	491,040	571,060
Ethanol (mil gal/yr)	489	112	344	400
3) Sugar cane first priority, trees second priority				
Sugar Acres	360,324	50,828	252,145	329,520
Wood Acres	394,136	115,488	288,105	294,564
Ethanol (mil gal/yr)	**705**	142	513	599
4) **Banagrass**				
Acres	360,324	50,828	252,145	329,520
Ethanol (mil gal/yr)	525	74	374	480

The first scenario with sugar cane as feedstock, including current gasoline demand, converted on a Btu basis to gallons of ethanol equivalent, is presented in Table 14. Results indicate that Hawaii, Maui, and Kauai counties collectively could potentially produce enough ethanol to match their current gasoline energy demand using NRCS-SS-ZA or NRCS-SS-ZA Agricultural Lands Important to the State of Hawaii (ALISH) lands. Maui and Kauai counties also could potentially meet gasoline demand with ethanol produced from sugar cane on NRCS-SS-ZA Large Land Owner (LLO) lands, and Kauai would have a surplus of 28 million gallons. Total potential ethanol production from NRCS-SS-ZA LLO lands would equal 45% of the 2005 state use. Total potential production from NRCS-SS-ZA State of Hawaii (SOH) lands equal 8.8% of the 2005 gasoline demand. Similar analyses were performed for woody biomass.

[36] Land use and zoning in Hawaii follow strict guidelines set forth in the State Land Use Law enacted in 1961. There are four zoning designations in the State of Hawaii: Agriculture, Rural, Urban and Conservation. This study looked only at land zoned for Agriculture. Using geographic information systems (GIS) software, different screening criteria were overlaid to assess the suitability and potential availability of lands for dedicated energy crop production.

[37] ALISH is defined as "agricultural lands important to the State of Hawaii." See "Accelerated Use of Renewable Resources for Transportation Fuels" for further details.

Table 13. Ethanol Potential in Hawaii from Sugar Cane Grown on Agriculturally Zoned NRCS Sugar Soils by Land Designation Compared with Actual Use

	Total Potential, Zoned Ag	Zoned Ag, State Owned	Zoned Ag, Large Land Owners	Zoned Ag, ALISH	Actual Usage in 2005[1]
Island	million gal/yr	million gal/yr	million gal/yr	million gal/yr	Gasoline million gal/yr as ethanol equivalent[2]
Hawaii	136.2	15.0	69.8	126.4	112
Maui	78.4	4.2	67.1	76.4	94
Lanai	13.1	0.0	13.1	11.9	-
Molokai	25.8	9.6	23.9	21.9	-
Oahu	82.9	5.3	67.8	72.6	440
Kauai	92.1	27.1	70.1	83.5	42
State Total	428.7	61.3	311.8	392.8	668

[1] Data from Hawaii Energy Data Book, http://www.hawaii.gov/dbedt/info/economic/databook/db2005/

[2] Gasoline sales by county converted to ethanol equivalent; 1 gal ethanol = 0.66 gal gasoline

Cost-effectiveness of producing ethanol in Hawaii was assessed by comparing cost of production against prices of imported ethanol. However, this does not internalize benefits that local production might accrue related to improved energy security, increased energy diversity, and stimulation of the state economy.

The average retail price for regular unleaded gasoline blended with 10% ethanol in Hawaii on December 1, 2006, was $2.86 per gallon (AAA 2008) and included taxes of $0.509 per gallon (Hao 2006), yielding a pretax retail value of $2.35 per gallon. This value would necessarily include dealer profits and other charges; however, it shows that ethanol produced for $1.50 per gallon could be competitively priced with gasoline on an energy-equivalent basis.

For purposes of the assessment, 2010 production of ethanol from molasses from existing sugar factories using readily available conversion technology was considered near-term. Production costs were estimated to be $1.45 to $1.58 per gallon. At $1.50 per gallon, ethanol from molasses would translate to $2.25 per gallon of gasoline on an energy-equivalent basis. Average retail gasoline prices without taxes were $2.35 per gallon on December 1, 2006, indicating that ethanol in Hawaii could be cost-competitive with gasoline under favorable market conditions. If ethanol were imported, its costs in Hawaii, based on west coast spot market prices plus shipping costs, range from $2 to $4.54 per gallon (excluding incentives), suggesting that ethanol produced from local feedstock could be more cost-competitive than importing it.

7.2 Biodiesel

Currently, all of the biodiesel produced in Hawaii (700,000 gallons) is from waste oil feedstock. By 2030, it is estimated that there will be enough waste cooking oil in Hawaii to produce 2 to 2.5 million gallons of biodiesel per year (Department of Environmental Management 2004). Examined separately from ethanol production (not taking into account potential competition for feedstock resources), findings of the assessments included:

- Given the absence of current agriculturally-based biodiesel production, estimates of future potential for biodiesel from agricultural feedstock are based on theoretical estimates. Further, the biodiesel and bioethanol estimates reported in the assessments were conducted independently, and the assessment cautions that a number of critical issues were not addressed in these initial estimates.[38]
- Major growth in the amount of biodiesel produced in Hawaii would only occur with the cultivation of dedicated oil crops or with the importation of agricultural feedstock. A recent study estimated that more than 160 million gallons of biodiesel could be produced from oil crops cultivated in Hawaii each year (Poteet 2006). However, none of the crops considered in the study are currently grown in Hawaii, except for small research quantities. Figure 21 illustrates biodiesel production potential (in 2030) from oil crops for each island, compared to recent petroleum diesel consumption.

[38] The estimates for bioethanol and biodiesel independently evaluated available land and, thus, “double counting” of land use would materially reduce the estimates. The results for ethanol and biodiesel are not additive. The commercial development of the crops and infrastructure supporting the production of these fuels will compete with one another. The land-use, water, and labor demands for each of these fuels will overlap. In addition, utilization of these same resources for other uses (food crops, residential development, etc.) was not factored into the analysis.

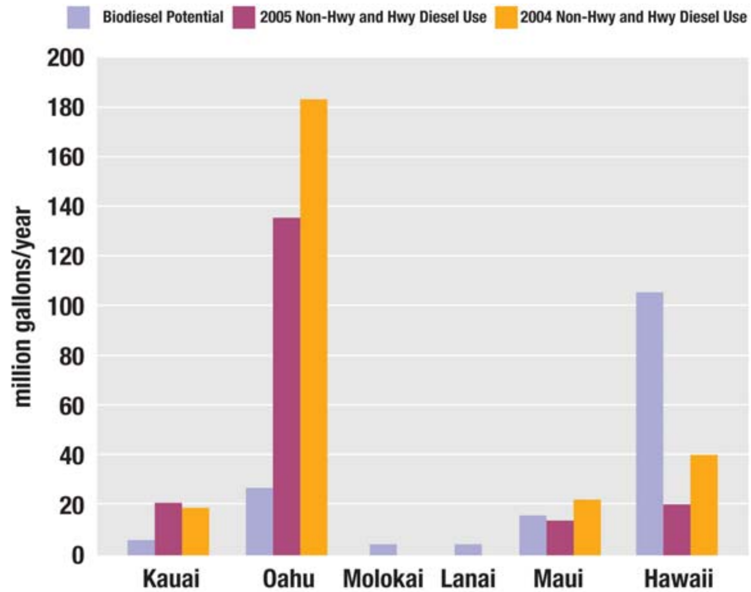


Figure 21. Hawaii's biodiesel production potential compared to historic demand for highway and non-highway diesel

7.3 Conclusions for Ethanol and Biodiesel

Technical assessments indicate that under a certain set of assumptions, ethanol production in the state has the potential to provide most, if not all, of the gasoline transportation fuel needs for the state. The technical potential for ethanol production included the evaluation of the spatial distribution of soil types, zoning, and annual rainfall using GIS technology. The Natural Resources Conservation Service (NRCS) designation for soil types suitable for specific crops—sugar cane and wood species—was used as a first identifier of land suitability. These lands were reduced by restricting consideration to the subset zoned for agricultural use. However, the technical potential estimates did not account for land-use priorities, impacts on environmental quality, economic impacts, food price and supply impacts for use of potential food croplands for energy feedstock production, and costs of production for ethanol conversion technologies that are currently in the development stage. Each of these merits additional study, whether for guiding future government policy-making or investing in ethanol production ventures. A similar conclusion cannot be reached for biodiesel fuel production. Feedstock to produce biodiesel for transportation fuels could be grown in the state. However, too little is known about the economics and the related agricultural requirements about any feedstock to make an accurate assessment as to the potential for future production.

In the ground transportation sector, in addition to initial blending of ethanol (E10), further demand for bioethanol will depend on consumer adoption of flex-fuel vehicles (FFVs) that can use a blend of up to 85% ethanol (E85), and the use of biodiesel in diesel vehicles. Only about 2% of Hawaii's vehicle fleet is E85 FFVs today. To meet the 20% state alternative fuel standard target, about 14% of the vehicle population would need to be FFVs by 2020 (DBEDT 2006a).

Lastly, use of sugar cane for ethanol production would further offset fossil fuel use in the electricity sector in Hawaii. According to recent estimates, each 10 million-gallon ethanol facility could potentially produce enough excess electricity to sell 2-2.5 MW (an estimated 14,610 to 17,520 MWh based on an 80% capacity factor) of renewable biomass power to the grid (DBEDT 2006a).[39] Therefore, the net oil reduction for ethanol facilities would be a combination of both the oil displaced by the ethanol fuel produced, and utility fuel oil displaced by electricity cogenerated by the ethanol production facilities and sold to the utilities.

7.4 Hydrogen

Hydrogen may be produced by different technologies, and with different primary energy sources. Specific to the renewable resources of Hawaii, hydrogen can be produced via electrolysis using electricity from solar, wind, geothermal, and hydropower; biomass can be used as a feedstock for thermochemical production of hydrogen. Additionally, LNG can be used as a feedstock for hydrogen production, although distribution of the LNG to small reformers, or distribution of the hydrogen from central reformers, is necessary.

Analysis of the production and use of hydrogen has been evaluated extensively by the DOE Hydrogen Program. Because of the extensive amount of renewable resources available in Hawaii, and the possibility of importation of LNG, hydrogen could be produced in Hawaii similar to the ways in which it is expected to be produced elsewhere. Thus, evaluations performed by DOE are directly applicable to the Hawaiian situation. Two primary modes of production can be envisioned:

- Central, large-scale production of hydrogen from LNG, biomass, or concentrated solar power, followed by distribution via pipelines or truck transport.
- Distributed production of hydrogen via electrolysis of renewable power from wind, solar photovoltaics, geothermal, or hydropower.

In each of these modes, storage of hydrogen could be accomplished at the point of production and on the vehicle (auto or boat). In the central production mode, hydrogen distribution infrastructure development and investment would be required.

An analysis of the price of hydrogen from indigenous renewable resources and LNG in Hawaii was completed. Results are presented in terms of the gallon of gasoline equivalent (gge) price of the hydrogen to the consumer, including a real (in 2005 dollars) 10% internal rate of return to the plant owner. The gallon of gasoline equivalent metric is based on the fact that one kilogram (kg) of hydrogen has approximately the same amount of energy as one gallon of gasoline. Efficiency improvements of future fuel cell vehicles over conventional internal combustion engines are not taken into account in the gallon of gasoline equivalent calculation. Thus, while the fuel cost can be compared to the cost of a gallon of gasoline, the per-mile cost is likely to be lower.

In the central generation cases studied (LNG reforming and biomass gasification/reforming), hydrogen distribution costs of $3.50/gge and $1/gge for the current and advanced cases,

[39] Electricity production is estimated at a rate of ~300 kWh/ton of bagasse, and consumed at a rate of ~150 kWh/ton.

respectively, are included in these costs. Storage costs for the distributed electrolysis cases are also included, and are calculated as part of the hydrogen analysis (H2A) model. [40]

Most commercial production of hydrogen today uses natural gas as a feedstock, although hydrogen is not currently produced in significant quantities in Hawaii. However, LNG-derived hydrogen was addressed as part of the assessments conducted to respond to the requirements of section 355 of EPAct. The delivered hydrogen price from reforming LNG at a central facility was calculated to be approximately $5.80/gge and $3.20/gge, using current and advanced (approximately 2015) technologies, respectively.

In addition, Table 15 summarizes the calculated selling price of hydrogen (using a 10% internal rate of return) from renewable resources in Hawaii. The cost of the renewable electricity or biomass being used in the production facility represents those reported elsewhere in this report, with the exception of the biomass feedstock cost, which is based on standard DOE Hydrogen Program assumptions.

Table 14. Fuel Cost Comparison of Various Hydrogen Pathways in Hawaii[41]

Technology	Type of Energy to Hydrogen Production System	Cost of Energy to Hydrogen Production System	Delivered Hydrogen Price Using Current Technology ($/gge)	Delivered Hydrogen Price Using Advanced Technology[42] ($/gge)
Wind / Electrolysis	Electricity	5-8 ¢/kWh	5.60 – 7.40	3.70 – 5.30
Solar PV / Electrolysis	Electricity	20-40 ¢/kWh	15.60 - 26.70	11.30 – 21.50
Concentrated Solar Power / Electrolysis	Electricity	12-18 ¢/kWh	9.80 – 13.40	7.30 – 10.30
Geothermal / Electrolysis	Electricity	4-7 ¢/kWh	5.0 – 6.80	3.20 – 4.70
Hydropower / Electrolysis	Electricity	4-7 ¢/kWh	5.0 – 6.80	3.20 – 4.70
Biomass Gasification and Reforming	Biomass Crop Residues	$15 – 38/bone dry ton	4.80 – 5.10	2.20 – 2.50

[40] DOE Hydrogen Program H2A models: 1) Current Central Hydrogen Production from Natural Gas without CO2 Sequestration version 1.0.9, and 2) Advanced Central Hydrogen Production from Natural Gas without CO2 Sequestration version 1.0.9. Values calculated are those reported in the Hydrogen, Fuel Cells & Infrastructure Technologies Program Multi-Year Research, Development, and Demonstration Plan (October 2007), modified to reflect projected LNG costs in Hawaii of $10.80/MMBtu.

[41] H2A Production Cost Model, based on current and advanced cases for distributed electrolysis and biomass (http://www.hydrogen.energy.gov/h2a_analysis.html), using U.S. Department of Energy Hydrogen Program Posture Plan, 2006, Appendix A assumptions (http://www.hydrogen.energy.gov/pdfs/hydrogen_posture_plan_dec06.pdf)..

[42] Advanced cases are from the H2A model cases modified to reflect the Department of Energy's Hydrogen Fuel Cells, and Infrastructure Technologies Program cost goals for technology installations past 2012, as per the Multi-Year Research, Development and Demonstration Plan: Planned Program Activities for 2005-2015, published October 2007, http://www.hydrogen.energy.gov/program_plans.html.

Because the June 2008 average retail price of gasoline in Hawaii is $3.96/gallon, hydrogen fuel from many renewable resources has the potential to be a cost-effective alternative on a fuel-to-fuel basis.

8. An Island-by-Island Approach to the Development of Hydrogen from Renewable Resources and the Application of Hydrogen to the Energy Needs of Hawaii

Section 355 (a) (6) of EPAct requires that the instant assessment address an island-by-island approach to the development of hydrogen from renewable resources and the application of hydrogen to the energy needs of Hawaii. A comprehensive study on the potential for hydrogen in the state of Hawaii was completed in 2002. Titled "Nurturing a Clean Energy Future in Hawaii: Assessing the Feasibility of the Large-Scale Utilization of Hydrogen and Fuel Cells in Hawaii," the report was produced by HNEI and Sentech (DBEDT 2002). No further assessment of the development of hydrogen from renewable resources was specifically conducted to address the requirements of section 355(a) (6). However, island-specific resource availability assessments for electricity production presented in Chapter 5 of this report are applicable to hydrogen potential, as hydrogen can be produced from any primary energy resource. Accordingly, the following discussion summarizes relevant findings, conclusions, and recommendations of published assessments, in conjunction with relevant assessments that were discussed in Chapter 5.

8.1 Findings

As a general matter, this report was subject to a number of uncertainties caused by the significant infrastructural and other barriers that will confront the introduction of any alternative energy option for the State of Hawaii.

This report evaluated several key uncertainties and determined their respective sensitivities to fueling-cost parameters. The uncertainties included feedstock costs, reformer efficiency, and hydrogen delivery costs for the LNG analysis; geothermal electricity cost, electrolyzer capital cost, electrolyzer efficiency, and hydrogen delivery cost for geothermal analysis; wind electricity cost, capacity factor, electrolyzer capital cost, electrolyzer efficiency, and hydrogen delivery costs for wind analysis; and biomass gasification costs and hydrogen delivery costs for biomass analysis. This sensitivity analysis reaffirmed that the assumptions used in the analysis on most of these parameters were conservative and that LNG-, geothermal-, and biomass-produced hydrogen can become competitive transportation fuels. The report also considered and compared island-by-island evaluations of both resource availability and market demand.

• The **Big Island (Hawaii)** possesses the greatest diversity of renewable resources, including solar, wind, biomass, and geothermal. It is the only island with a geothermal power plant, and its electricity demand patterns typically yield available off-peak electricity that could be used to make hydrogen. Much of the economic growth on the island centers on the commercial development on the Kona coast of the island. This region contains an airport, Natural Energy Laboratory, commercial resorts, commercial agriculture, and a burgeoning tourist industry from which an integrated hydrogen energy project can be developed.

• **Oahu** contains the greatest population and the urban center of Honolulu—this represents the greatest opportunity to use hydrogen and fuel cells. Transportation applications, including tourist transport, military transport, airport support vehicles, and other fleet applications create a large opportunity for a hydrogen-fueled fleet. Urban power issues such as transmission limitations, power quality, and commercial peak power create additional opportunities for stationary fuel cells. Unfortunately, electricity demand patterns and limited availability of renewable resources makes it a less than ideal place to produce hydrogen. Some hydrogen is available from the existing refinery and synthetic natural gas production. This hydrogen may be useful for near-term projects, but will not offer the energy security benefits desired in the long term.

• Both **Maui** and **Kauai** have significant biomass, solar, and wind resources. Large biomass availability makes hydrogen gasification an attractive option. A dispersed population makes transportation and utility (domestic) uses the highest likely value. Additionally, the feasibility of "importing" hydrogen from the Island of Hawaii to these islands should be explored.

Finally, the study addressed a number of additional challenges to hydrogen fuel development in Hawaii. For example, although LNG may represent an opportunity to serve the urban areas of Honolulu, it poses many of the same problems for Hawaii as other petroleum-based fuels (i.e., it must be imported, it still creates greenhouse gas emissions, and it is subject to even greater price volatility on the world market). Additionally, no LNG infrastructure exists on the Islands. Biomass resources are extensive on all islands except Oahu, and could potentially fuel the entire state's automotive fleet. Increasing levels of experience worldwide with biomass collection, processing, and thermochemical conversion to hydrogen and biofuels yearly reduces the risks of such an option. The Big Island of Hawaii has commercial geothermal energy plants and even greater (>200 MW) potential to develop more plants to produce hydrogen via electrolysis, but its limited population and large size limit the application and utility of the hydrogen option unless inter-island transport of hydrogen becomes feasible.

8.2 Recent Activity

The report concluded with several recommendations. Several of these have been addressed in the past few years. While the report called for engineering and market studies for each of the islands, such efforts have focused on activity on the more populated islands. In 2005, DOE helped establish the Hawaii Hydrogen Center (HHC) for Development and Deployment of Distributed Energy Systems. The HHC, one of HNEI's largest projects, receives DOE funding and carries out activities such as augmentation of the Hydrogen Power Park[43], assessment of hydrogen fuels purity requirements for fuel cell applications, R&D of cost-effective renewable hydrogen production, and analysis of potential hydrogen and distributed energy systems for the Big Island grid system.[44] A variety of subcontracts are involved, using several industrial companies and educational organizations.

HNEI is continuing its efforts to develop large-scale hydrogen and distributed energy demonstration projects. Much of this work is focused at the recently constructed Hawaii Gateway Energy Center on the Big Island of Hawaii. Separately, with funding from the Office of Naval Research (ONR) and other sources, HNEI has a program focused on the development and

[43] The Hydrogen Power Park is funded by DOE and managed by the Hawaii Natural Energy Institute at the Kahua Ranch on the Island of Hawaii. This project examines the potential for integrating renewable energy systems to produce hydrogen.

[44] http://www.hydrogen.energy.gov/pdfs/progress05/viii_b_1_rocheleau.pdf.

testing of polymer electrolyte membrane (PEM) fuel cells. In 2003, the Hawaii Fuel Cell Test Facility (HFCTF) began operations. Current activities at the HFCTF include characterization of the effect of trace impurities on PEM fuel cell performance, characterization of alternative membrane technologies, and testing of fuel cell stacks for undersea vehicle applications.

CONCLUSIONS

Hawaii is the most heavily dependent state on imported energy. As of 2007, Hawaii relied on oil, all of it shipped into the state, for nearly 90% of its energy needs. Eighty-three percent of electric generation is oil-fired in Hawaii, and the state has the highest electricity costs in the United States. Prices of gasoline and electricity have both risen over 100% since 2003. Gasoline prices rose from a low of $1.78/gallon in January 2003 to a high of $3.96/gallon in June 2008. Residential electricity rates rose from 18.5¢/kWh in 2003 to over 24¢/kWh in late 2007. Overall, Hawaii has the highest average electricity prices in the country, currently at 18.7¢/kWh compared with the national average of 8.8¢/kWh.

Hawaii's natural resource base, combined with its unique energy challenges, creates an opportunity for the state. As this report demonstrates, Hawaii has many opportunities to diversify energy use through greater utilization of renewable energy for electricity and transportation applications. Natural gas could also play a part in diversifying Hawaii's energy mix, as the state weighs its possible approaches to combating high oil prices.

Under the current energy structure, disruption in a stable supply of petroleum is an acute risk to the state. Petroleum-based fuel dominates transportation energy consumption as well as electricity production. Any supply disruption would potentially cascade through the majority of the economy of the state, including dependent industries such as tourism. The timing of oil supply disruption impacts would depend on available storage and the ability of the state to import refined product.

The economic relationship between oil prices and the economy of Hawaii is complex. Increases in gross state product appear to have slowed with recent sharp increases in oil prices. The GSP increased 10% from 2003 to 2004 but increased approximately 6% from 2005 to 2006. During this time, oil prices increased from $30/bbl to $100/bbl. The analysis in this report identifies several economic areas that would be most impacted if the supply of oil to the state was disrupted—a disruption that could be mitigated by greater reliance on indigenous energy generation.

Initial assessments have identified renewable resources in Hawaii with the potential for more than 2,000 MW nameplate generating capacity. Inclusion of distributed solar power from rooftops increases the total to more than 4,000 MW of nameplate capacity. For general sense of scale, the current installed electric generation nameplate capacity in Hawaii is 2,414 MW, though these capacity figures cannot be directly compared as the variability of wind and solar generation leads to lower energy output on average than the current installed generation mix. Further, while the island of Oahu consumes nearly 60% of the state's electricity and is not electrically interconnected with the outer islands, less than 60 MW of the identified renewable potential is located on Oahu. A number of factors were identified that should be addressed to realize this potential, including solutions to the challenges of maintaining grid stability and reliability with increasing variable generation, and developing business models via legislative, regulatory, and utility action that appropriately support renewable energy development. Additionally, the small scale of most individual island power grids and lack of interconnection among the islands pose unique technical and commercial challenges for significant use of renewable power sources.

Another alternative to crude oil imports for Hawaii's energy needs is imported natural gas. As no LNG import facility exists today, significant capital investment and at least three years to build the necessary infrastructure would be required to use LNG resources. If LNG were transported to Hawaii, the share of primary energy supplied by petroleum could be reduced by approximately 20% within four to seven years of a decision to move forward. While natural gas may be obtained from a variety of supply sources, including Australia or domestic sources such as Alaska, the state would still be relying upon fuel that must be shipped into the state. However, the small market size of the state, with the limited growth potential, and the expense and difficulty of establishing a receiving terminal were identified as the main disadvantages of Hawaii as an LNG market.

Use of biofuels and hydrogen for transportation was found to be technically feasible for a few select pathways, including ethanol from numerous non-food sources and biodiesel. Hydrogen could be derived from a number of different indigenous energy sources including wind, solar, and geothermal.

Currently, state, national, and global policy trends are driving the change to utilize more renewable energy. On the state level, Hawaii has enacted numerous policies that promote renewable energy and fuels development, including a renewable portfolio standard to produce 20% of state electricity from renewable energy sources by 2020 and an alternative fuels standard that aims to provide 20% of the state's highway fuel demand from alternative fuels by 2020. Investment tax credits for ethanol that are legislated on the state level combine with federal incentives for ethanol blending and retailing (the federal Volumetric Ethanol Excise Tax Credit) to create robust financial incentives for biofuel production and use. The federal renewable energy production and investment tax credits also encourage the installation of renewable energy within the state.

The HCEI is a significant program that will continue to expand Hawaii's use of renewable resources and reduce the state's dependence on oil. The HCEI is a joint collaboration established through an MOU signed in January 2008 between DOE and the State of Hawaii[45]. The goal of the HCEI is to achieve 70% of the state's primary energy from clean energy sources by 2030. If met, this goal would reduce Hawaii's overall consumption of crude oil up to 72%. With on-the-ground DOE support in Hawaii, DOE and Hawaii have already begun to work collaboratively to stimulate advances in the areas of end-use efficiency, grid integration and storage, grid modeling, policy transformation, and biofuels production.

If Hawaii is successful in its HCEI efforts, it could serve as an integrated model and test bed that demonstrates how to expand the penetration of renewable energy and strategically reduce oil dependence. Reduction in oil consumption may result in positive economic, environmental, and energy security gains for the state. The options identified in this report should be further investigated and merged with the development goals of the state to design a more secure and profitable energy future.

[45] See Appendix D on page 62 of this report.

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APPENDIX A

Summary of Molokai Renewable Power Preliminary Analysis

Maui Electric Company data was used to analyze increasing levels of wind power for Molokai. Preliminary analysis indicated that increased use of wind could be cost-effective. It is estimated that diesel fuel use could be reduced from 38% to 70% with overall life-cycle cost savings between 20% and 40%.[46] Other renewable energy technologies, such as flat-plate photovoltaic systems and biomass were not found to be as economic as wind or diesel power.

The analysis for Molokai also highlighted some areas requiring additional analysis, including grid stability issues associated with wind variability and intermittency. Practical feasible capacity of wind generation would depend on how the utility handles integration issues, such as spinning reserves, advanced generation controls, and operations and maintenance issues associated with running diesel generators at lower load levels. It should be pointed out that this analysis did not attempt to treat the Molokai grid as part of the larger Maui electric company system. Rather, this was examined as a stand-alone system.

Several cases were run to test the sensitivity of the results to several variables. The ranges analyzed reflect resource and cost uncertainties, as well as elements embedded in decisions that MECO must make over how to dispatch the diesel generators within their system, which can have a substantial effect on the integration of wind power into the system. As shown in Figure A1, the optimal number of 1.5-MW turbines varies from three to six, and the resulting fuel consumption varies from 3,480,000 liters to 7,211,000 liters. This represents a potential savings of 34% to 68% compared to the current diesel fuel consumption of approximately 11,000,000 liters.

MECO must maintain operating reserves to cover both increases in the load and decreases in the power output of the wind turbines. This was modeled by requiring the operating capacity to be greater than the load plus the operating reserves. The operating capacity is equal to the sum of the wind output in a particular hour, plus the maximum capacity of the diesel generators that are operating in that hour even if the output of the generators in that hour is less than their maximum capacity. If the operating reserve relative to wind power is set to 100%, the system could lose all of its wind power within that hour and still be able to meet the load. In that scenario, the diesels are dispatched without regard to the wind turbines. Based on conversations with MECO, it was decided to also model cases with reduced operating reserves sufficient to cover the unexpected loss of 50% of the wind capacity within an hour.

A simultaneous sensitivity was performed on the diesel minimum load. This is a constraint that prevents the diesels from ever operating below that level. To maintain this constraint it may be necessary to curtail wind power or send electricity to an alternate load ("dump," or hydrogen production or other storage technologies). Additional analysis would be required to consider scenarios where this excess energy would be used for water pumping or other deferrable loads.

[46] Analysis was conducted with the HOMER model, using hourly data. Further description is available at www.nrel.gov/homer.

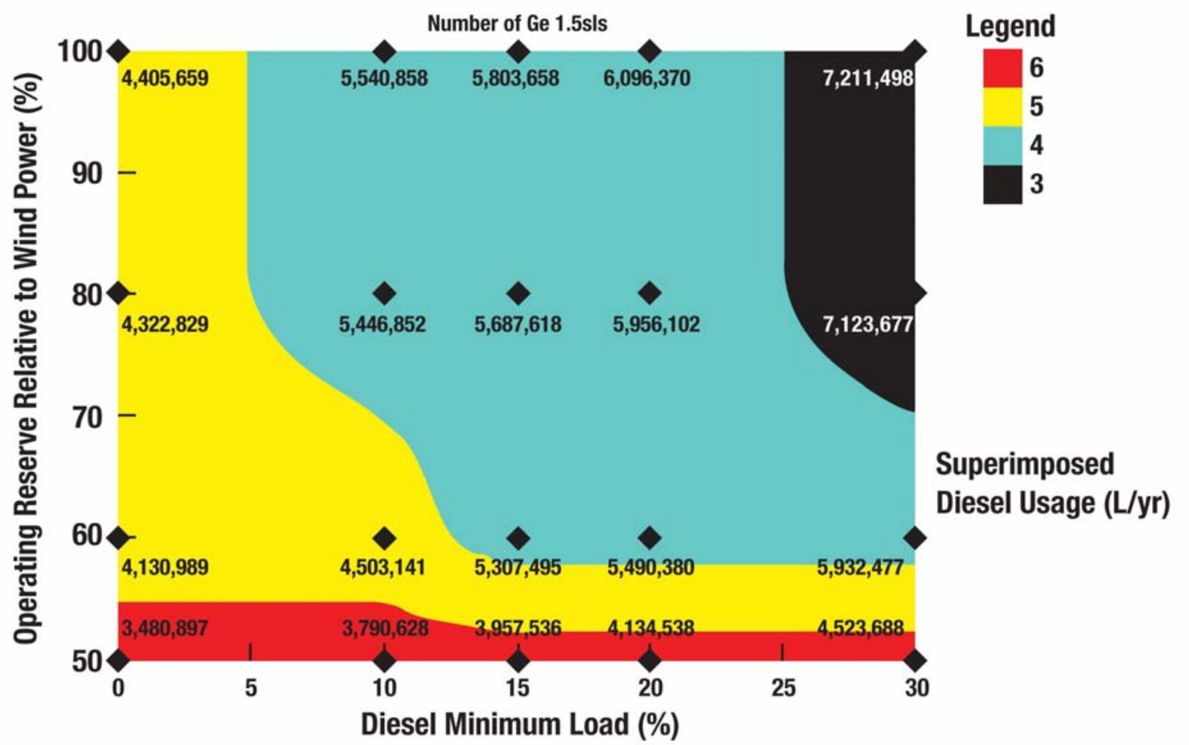

Figure A1. Operating reserve versus diesel minimum load

A further discussion of the wind results follows. For the base case, wind data were used from Niftal, a wind-monitoring site on Maui, with an assumed 50% operating reserve and a minimum allowable load on the generator of 15% (as a percentage of its rated capacity). Figure A2 details the interplay between cost, diesel fuel use, and excess electricity.

It can be seen that the least-cost scenario is comprised of six turbines. Intuitively, as the number of turbines increases, the diesel fuel use decreases due to the production of wind to offset diesel fuel use. However, excess electricity production impacts the system economics. The first three to four turbines displace fuel consumption at a constant rate because the system is able to use all of the wind output. Above four turbines, the rate of fuel savings drops off because the system is not able to use the wind energy that is produced when the wind is high and the load is low.[47]

A sensitivity analysis was also performed using Puunene wind data, which is the lowest wind resource of the nine Hawaii sites. This analysis was done to examine the effect of a lower wind resource on the feasibility of wind turbines on Molokai. The results show that wind turbine deployment on Molokai would still be cost-effective. However, the least-cost system comprises four turbines and uses almost 7.5 million liters of fuel when a weaker wind resource is available.

[47] Calculations were performed on an hourly time scale for a typical year.

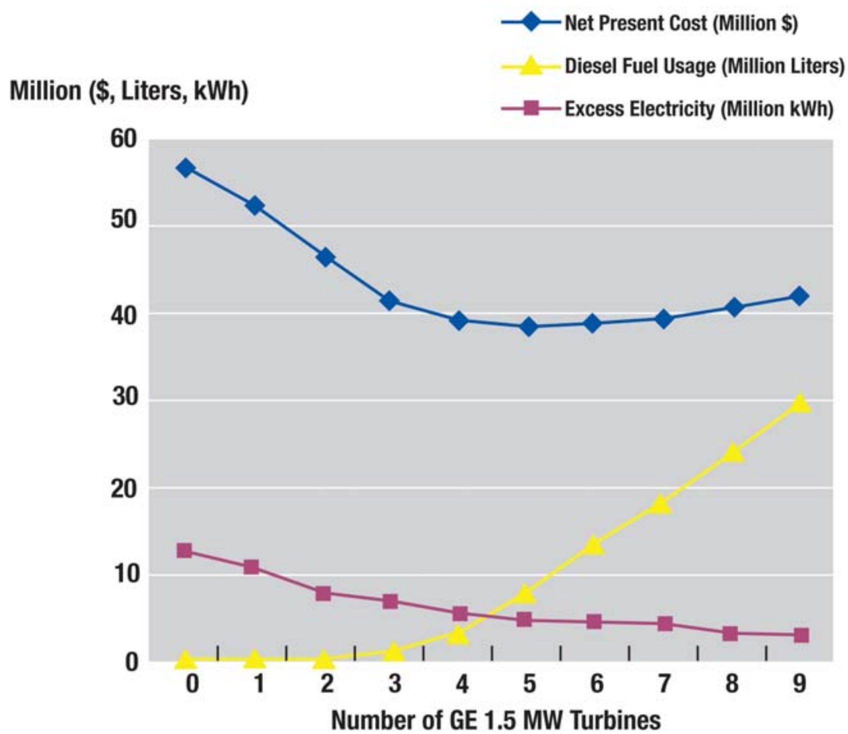

Figure A2. Molokai 50% operating reserve, 15% min. load, $0.35/liter fuel price

Preliminary analysis was performed on the cost-effectiveness of photovoltaic (PV) systems. A sensitivity analysis was performed that illustrated that PV was not part of the optimal solution until its capital cost was less than $1.50 per watt, including inverter and installation costs. The exceptionally good wind resource reduces the comparative cost-effectiveness of PV. When all of the cost-effective wind is installed, there are substantial periods of time when excess energy is available. During these periods, any power produced by PV would not be usable. These results could change with the use of more load management or storage and could be examined further in a more detailed analysis.

APPENDIX B

Section 355 of the Energy Policy Act of 2005

Sec. 355. ASSESSMENT OF DEPENDENCE OF STATE OF HAWAII ON OIL

(a) ASSESSMENT.—The Secretary of Energy shall assess the economic implications of the dependence of the State of Hawaii on oil as the principal source of energy for the state, including—

> (1) the short- and long-term prospects for crude oil supply disruption and price volatility and potential impacts on the economy of Hawaii;
>
> (2) the economic relationship between oil-fired generation of electricity from residual fuel and refined petroleum products consumed for ground, marine, and air transportation;
>
> (3) the technical and economic feasibility of increasing the contribution of renewable energy resources for generation of electricity, on an island-by-island basis, including—
>
> > (A) siting and facility configuration;
> > (B) environmental, operational, and safety considerations;
> > (C) the availability of technology;
> > (D) the effects on the utility system, including reliability;
> > (E) infrastructure and transport requirements;
> > (F) community support; and
> > (G) other factors affecting the economic impact of such an increase and any effect on the economic relationship described in paragraph (2);
>
> (4) the technical and economic feasibility of using liquefied natural gas to displace residual fuel oil for electric generation, including neighbor island opportunities, and the effect of the displacement on the economic relationship described in paragraph (2), including—
>
> > (A) the availability of supply;
> > (B) siting and facility configuration for onshore and offshore liquefied natural gas receiving terminals;
> > (C) the factors described in subparagraphs (B) through (F) of paragraph (3); and
> > (D) other economic factors;
>
> (5) the technical and economic feasibility of using renewable energy sources (including hydrogen) for ground, marine, and air transportation energy applications to displace the use of refined petroleum products, on an island-by-island basis, and the economic impact of the displacement on the relationship described in paragraph (2); and
>
> (6) an island-by-island approach to—
>
> > (A) the development of hydrogen from renewable resources; and
> > (B) the application of hydrogen to the energy needs of Hawaii.

(b) CONTRACTING AUTHORITY.—The Secretary of Energy may carry out the assessment under subsection (a) directly or, in whole or in part, through 1 or more contracts with qualified public or private entities.

(c) REPORT.—Not later than 300 days after the date of enactment of this Act, the Secretary of Energy shall prepare (in consultation with agencies of the State of Hawaii and other stakeholders, as appropriate), and submit to Congress, a report describing the findings, conclusions, and recommendations resulting from the assessment.

(d) AUTHORIZATION OF APPROPRIATIONS.— There are authorized to be appropriated such sums as are necessary to carry out this section.

APPENDIX C

Energy Policy and Conservation Act Provisions for Offering Hawaii Petroleum Product during a Drawdown of the Strategic Petroleum Reserve

The Energy Conservation Reauthorization Act of 1998 (Public Law 105-388) amended the Energy Policy and Conservation Act (EPCA) (42 U.S.C. 6201, et seq.), to give Hawaii assured access to Strategic Petroleum Reserve (SPR) oil in the event of a severe energy supply interruption. Specifically, a new subsection 161 (j), (42 U.S.C. 6241 (j)) was added which provides, among other things, that:

1. In addition to submitting an outright competitive bid, Hawaii, or its designated eligible entity, may submit a binding offer for Strategic Petroleum Reserve crude oil in the event of an SPR drawdown and sale;

2. The price for oil purchased by Hawaii by a binding offer will be the volumetrically weighted average price of the successful competitive offers for the applicable category of oil;

3. At the request of the Governor of Hawaii, SPR oil purchased by Hawaii at a competitive sale or through a binding offer shall have priority in SPR scheduling of deliveries; and

4. Hawaii may enter into exchange or processing agreements to permit delivery to other locations, if a petroleum product of similar value or quantity is delivered to the State.

Section 161(j) further defines “eligible entity” as an entity that owns or controls a refinery located in Hawaii, and may be certified by the Governor of Hawaii to act on the State’s behalf under the section. A “binding offer” is defined as a bid submitted by Hawaii for an assured award of a specific quantity of petroleum product, with a price to be calculated as described in item 2 above, and that obligates the offeror to take title to the petroleum product without further negotiation or recourse to withdraw the offer. The State is limited to no more than one eligible entity per SPR sales offering.

The law provides that the Department of Energy (DOE) may limit the quantity of SPR oil to be purchased by Hawaii based on the lesser of Hawaii’s average monthly oil imports for a recent representative period, or three percent of the total quantity to be offered for sale by DOE. The SPR current maximum drawdown capability is 4.4 million barrels per day, so the maximum amount to be made available to Hawaii would be approximately 135,000 barrels per day or a total of four million barrels over a nominal 30-day sales cycle.

To implement the provisions of subsection 161(j) the Department of Energy and the State of Hawaii executed a Memorandum of Understanding (MOU) in September 1999. Under Chapter 125C, Hawaii Revised Statutes (HRS), entitled Procurement, Control, Distribution and Sale of

Petroleum Products, sections 125C-3 (6) and (7) authorize the Governor of Hawaii or the Governor's "authorized representative", among other things, to contract in the name of the State to exercise their powers during a petroleum shortage, as well as to exercise their granted powers to the degree and extent deemed necessary. HRS section 125C-31 (a)(1) identifies the Director of Business, Economic Development and Tourism, in their capacity as Hawaii's energy resources coordinator, as the Governor's "authorized representative" and thus the State's coordinator under this MOU.

The MOU remains in effect and has provided the basis for Hawaii's participation in several SPR simulated drawdown training exercises; however Hawaii did not chose to submit a binding offer during the 2005 Hurricane Katrina drawdown.

During discussions, the State and representatives from both Chevron and Tesoro have voiced concerns on whether this legal framework actually facilitates the provision of emergency supplies. Both refiners have commented that being limited to the purchase of one SPR crude oil stream would not be practical for their refining purposes. More important is the limited likelihood that any SPR crude oil would actually be transported from the U.S. Gulf region to Hawaii. While Section 161(j) provides for the State to have first preference in scheduling for lifting, the transit time would still result in arrival at the State nearly four weeks after the President's directive to drawdown.

In addition, both refiners have expressed concern that competitive pricing in the U.S. Gulf-based sale is at odds with their refinery economics. This disconnect is further complicated by not knowing the actual price until after the weighted average of other purchasers has been determined, which is then compounded by the added cost of long-haul shipping. On top of this price uncertainty is the stipulation that a binding offer cannot be withdrawn, so there is real risk that may preclude either Hawaii refinery from participating.

For this reason, all parties recognize that the designated entity would most likely enter into a processing agreement or other trade arrangement for oil or product to be delivered to the State. Chevron, having a Gulf Coast refinery, may be in a better position to effect such an arrangement. How the State would determine if that is actually accomplished and whether the full value accrues to the State is an outstanding issue.

APPENDIX D

MEMORANDUM OF UNDERSTANDING BETWEEN THE STATE OF HAWAII AND THE U.S. DEPARTMENT OF ENERGY

I. Background

The State of Hawaii depends on imported fossil fuels to meet over 90 percent of its energy needs. This dependence leaves Hawaii vulnerable to supply disruptions and high energy prices with estimates showing that every 10 percent increase in world oil prices results in a 0.5 percent reduction in the State's GDP.

At the same time, the islands of Hawaii have abundant natural resources, including wind, sunshine, and geothermal sources for electricity generation, and land for energy crops that can be refined into biofuels to address transportation needs. Economic and culturally sensitive use of natural resources can provide energy supply security and price stability for the people of Hawaii as well as significant environmental benefits and economic growth opportunities. Successfully developing Hawaii's energy economy will make the State a global model for achieving a sustainable, clean, flexible, and economically vibrant energy future.

The State, counties, utilities, private sector, non-governmental organizations, and other entities are taking steps to decrease State-wide energy use through the investment in and utilization of efficiency technologies while also increasing development of renewable energy projects. Projections indicate that current plans and development activities could result in approximately 20 percent of the electric energy supply generated from renewable resources by 2020. However, even achievement of this goal will still leave the State heavily dependent on imported fossil fuels and subject to supply disruptions.

It is estimated that Hawaii can potentially meet between 60 and 70 percent of its future energy needs from clean, renewable energy sources. However, achieving this level market of penetration will require substantive transformation of the financial, regulatory, legal, and institutional systems that govern energy planning and delivery within the State.

II. Purpose

The purpose of this Memorandum of Understanding (MOU) is to establish a long-term partnership between the State of Hawaii and the U.S. Department of Energy (DOE) that will result in a fundamental and sustained transformation in the way in which renewable energy efficiency resources are planned and used in the State. Successful development and execution of the objectives contemplated in this partnership will provide a replicable global model for achieving similar results.

The DOE-Hawaii Partnership will build upon the dynamic, ongoing work of public and private organizations at the State, county, and grassroots levels in order to achieve several key goals:

- *To define the structural transformation* that will need to occur to transition the State to a clean energy dominated economy
- *To demonstrate and foster innovation* in the use of clean energy technologies, financing methodologies, and enabling policies designed to accelerate social, economic and political acceptance of a clean energy dominated economy
- *To create opportunity at all levels of society* that ensures wide-spread distribution of the benefits resulting from the transition to a clean, sustainable energy State
- *To establish an "open source" learning model* for others seeking to achieve similar goals
- *To build the workforce with crosscutting skills* to enable and support a clean energy economy.

III. Collaboration

The State of Hawaii and DOE will each accept the following roles and responsibilities to meet the goals of this MOU to the extent practical and authorized by law to:

(A) Together

- Agree on near-term goals that demonstrate the accelerated deployment strategies anticipated herein and work collaboratively to support the implementation of these goals
- Develop a set of intended outcomes and designate working groups to produce long-term clean energy deployment plans in each of the major energy performance areas articulated in the Appendix to this MOU
- Designate points of contact for overall collaboration, as well as for each of the energy performance areas listed below
- Produce strategic plans for review and comment by the public
- Support communications and education campaigns that inform consumers, businesses, and major stakeholders in Hawaii of the goals and benefits of this initiative.

(B) DOE

- Serve as a conduit between the State of Hawaii and the appropriate organizational entities (such as DOE national labs, Federal programs, research and development entities, and operations organizations) that can facilitate the strategic planning process and contribute to the execution of core activities within each of the energy performance areas
- Designate a lead for each energy performance working group and cross-cutting issue working group responsible for working with the State to coordinate the activities of the working group
- Provide technical assistance to the State for producing the technical and economic tools necessary to realize the goals of the initiative, as well as coordinate pilot activities to enhance the sustainability of these activities
- Facilitate participation of national, non-governmental entities in the initiative.

(C) State of Hawaii

- Identify the critical State-based stakeholders needed to participate in the working groups

- Establish the State-mandated processes needed to review and ultimately enact the policies, educational programs, and other provisions of the strategic plans within each of the energy performance areas listed below
- Promote the goals and recommendations of the working groups to consumers, businesses, and other organizations within the State to ensure that the transformational goals are broadly understood and embraced by the greatest cross section of the State's population possible
- Develop the technical and economic tools necessary to realize the goals of the initiative.

Additional details regarding plans for implementing this MOU are set forth in the attached Appendix, entitled "Structure and Time Frames the DOE-Hawaii Clean Energy Partnership." The Appendix is hereby incorporated by reference in this MOU and is subject to all terms thereof.

IV. General

(A) This MOU and the attached Appendix are strictly for internal management use of each of the parties. It is not legally enforceable and shall not be construed to create any legal obligation on the part of either party. This MOU and the attached Appendix shall not be construed to provide a private right or cause of action for or by any person or entity.
(B) This MOU and the attached Appendix can be terminated by either party at any time by providing notice in writing to the other party.
(C) This MOU and the attached Appendix in no way restrict either of the parties from participating in any activity with other public or private agencies, organizations or individuals.
(D) This MOU and the attached Appendix are neither fiscal nor funds obligation documents. Nothing in this MOU authorizes or is intended to obligate the parties to expend, exchange, or reimburse funds, services, or supplies, or transfer or receive anything of value.
(E) This MOU and the attached Appendix shall not be construed to impact procurement or financial assistance activities of either DOE or the State of Hawaii.

The Department of Energy enters into this MOU under the authority of section 646 of the Department of Energy Organization Act (Pub. L. 95-91, as amended; 42 U.S.C. § 7256).

All agreements herein are subject to, and will be carried out in compliance with, all applicable laws, regulations and other legal requirements.

DEPARTMENT OF ENERGY	THE STATE OF HAWAII
By [signature]	By [signature]
Print Name: Alexander A. Karsner	Print Name: Linda Lingle
Title: Assistant Secretary Energy Efficiency and Renewable Energy	Title: Governor of Hawaii

<u>Appendix [to Memorandum of Understanding]</u>

<u>Structure and Time Frames for the DOE-Hawaii Clean Energy Partnership</u>

The joint actions by Hawaii and DOE under consideration will fall into several categories:

1. Establishment of Short-, Medium- and Long-Term Clean Energy Deployment Plans (2008-on)

Hawaii and DOE plan to establish working groups in each of the energy and cross-cutting focus areas identified below. The objective of these groups will be to define, in specific detail, the structural, technical, regulatory, financial and other barriers that would prevent the state from achieving—and maintaining—its clean energy potential, as defined in this document.

Energy Performance Working Groups will address:

- ***End-use efficiency***, with the ultimate goal of achieving zero net-energy buildings and communities, and dramatic reductions in other significant end-use areas, including military bases and installations;
- ***Electric generation***, including expanding and optimizing the use of renewable energy at central and remote locations, improving generation efficiency at existing plants, and facilitating the installation of distributed renewable generation across the State;
- ***Energy delivery,*** including transmission and distribution improvements, grid management improvements, and energy storage to ensure that the existing and future infrastructure facilitates optimal use of renewable resources and readily adapts to and incorporates new developments in system planning and transmission technologies while maintaining system reliability; and
- ***Transportation***, including the establishment of a long-term, sustainable strategy for the production, distribution, and use of alternative transportation fuels, thereby accelerating the adoption of advanced vehicle technologies such as plug-in hybrids, and promoting mass transit.

Cross-Cutting Issue Working Groups will consider addressing:

- ***Technology integration,*** including consideration of current clean energy technologies that have been demonstrated in Hawaii and elsewhere, state of the art technologies that have not yet been demonstrated on the commercial scale, integration of transportation and electricity energy systems, and solutions for technology reliability and economic viability;
- ***Creating sustained sources of financing***, with particular emphasis on developing innovative public and private financing vehicles for alternative energy sources and clean technologies at the state and county levels; and

- ***Policy and regulatory mechanisms***, including design and enactment of comprehensive regulatory mechanisms that provide appropriate incentives for all stakeholders in the energy supply chain to proactively transition to a renewable energy-based future.

The working groups will be co-chaired by the State and DOE, with the mandate to produce two-, five- and ten-year operational plans to transform the investment in and use of energy resources in each energy performance area. These plans will include date-specific goals for major actions and mechanisms for leveraging the expertise, creativity, and resources of the major stakeholders.

The planned timeline for producing and executing the strategic plans is as follows:

- **January 2008**: Launch DOE-Hawaii Partnership and establish working groups in each of the working group areas outlined above.
- **March 2008**: Issue draft strategic implementation plans in each of the working group areas.
- **June 2008**: Issue final strategic implementation plans that include a set of initial actions needed to jump start activity in each of the energy performance areas, two-, five- and ten-year goals, and specific actions that will be taken to meet the transformational goals required in each of the major areas.

2. Institutionalization of Financial, Policy, and Regulatory Mechanisms Needed to Transition to a Clean Energy Future (2009-on)

The results of the deployment planning and pilot activities articulated in the first two stages of this initiative should identify a set of financial, regulatory, and policy activities that should pursued in Hawaii over the long-term to ensure a sustainable energy future. In addition, working groups may identify key education and training activities that are needed to develop and maintain well-functioning energy infrastructure on a very large scale in each of the Hawaiian islands. Through this process, the State and DOE agree to have a standing committee to identify these needs and to promote their adoption by the relevant state and/or federal agencies involved.

3. Communicating the Goals, Benefits, and Accomplishments of this Partnership with Citizens of Hawaii, the United States, and the Pacific Rim (2007-on)

Both parties will seek to work collaboratively to establish multi-stakeholder outreach campaigns that highlight the economic, environmental, security, and other benefits of the transition to a clean energy future in Hawaii. These campaigns should be on-going throughout the process and specifically designed to provide pertinent, actionable information to consumer, trade, education, business, and other groups in Hawaii as well as throughout the U.S., the Pacific Rim, and the world.