The Potential of Renewable Energy to Reduce the Dependence of the State of Hawaii on Oil

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Abstract

Deriving nearly 90% of its primary energy resources from oil, the State of Hawaii is more dependent on oil than any other U.S. state. The price of electricity in Hawaii is also more than twice the U.S. average. The Energy Policy Act of 2005 directed assessment of the economic implications of Hawaii's oil dependence and the feasibility of using renewable energy to help meet the state's electrical generation and transportation fuel use. This paper is based on the assessments and report prepared in response to that directive.

Current total installed electrical capacity for the State of Hawaii is 2,414 MW_e, 83% of which is fuel-oil generated, but already including about 170 MW_e of renewable capacity. The assessments identified about 2,133 MW_e (plus another estimated 2,000 MW_e of rooftop PV systems) of potential new renewable energy capacity. Most notable, in addition to the rooftop solar potential, is 750 MW_e and 140 MW_e of geothermal potential on Hawaii and Maui, respectively, 840 MW_e of potential wind capacity, primarily on Lanai and Molokai, and one potential 285 MW_e capacity specific solar project (PV or solar thermal) identified on Kauai. Important social, political, and electrical-grid infrastructure challenges would need to be overcome to realize this potential.

Among multiple crop and acreage scenarios, biofuels assessment found 360,000 acres in Hawaii zoned for agriculture and appropriate for sugarcane, enough to produce 429 million gallons of ethanol—enough to meet about 64% of current 2005 Hawaiian gasoline use. Tropical oil seed crops—potentially grown on the same land—might meet a substantial portion of current diesel use, but there has been little experience growing such crops in Hawaii.

The U.S. Department of Energy and the State of Hawaii initiated in January 2008 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. The Hawaii Clean Energy Initiative (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; and 2) Partnership Projects will be undertaken with local and mainland partners that demonstrate and commercialize new technologies and relieve technical barriers.

Index Terms

Hawaii, Renewable Energy, Renewable Electrical Generation, Renewable Transportation Fuels, Oil Dependence

1. Introduction

Deriving nearly 90% of its primary energy resources from oil, the State of Hawaii is more dependent on oil than any other U.S. state. While that oil includes U.S.-refined product and crude oil from Alaska, none of it is mined within the state and 75% of it is imported from other countries. With 83% of electrical production based on fuel oil, the price of electricity in Hawaii is also more than twice the U.S. average. With relatively little oil product-related industry and a high proportion of tourism-based industry, the 2005 percentage of expenditures within the state on fossil fuel products was relatively low at 1.4% (compared to 4.8% nationally). Nonetheless, the Hawaiian economy is heavily tied to fossil fuel-product use. Indeed, the growth in gross state product decreased from a high of 10% from 2003 to 2004 to approximately 6% from 2005 to 2006 as oil prices increased from

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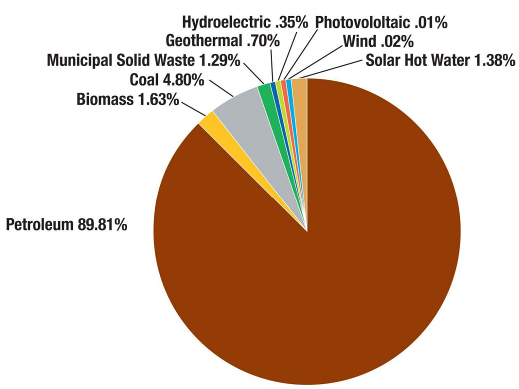
$30/bbl to $100/bbl. Industries that would be particularly impacted by curtailment of oil imports include air and water transportation by fuels, real estate other than hotels and motels, hotels and motels by electricity, and other state and local government enterprises by both.

Section 355 of the Energy Policy Act of 2005 directed the U.S. Secretary of Energy to assess the economic implications of the dependence of the State of Hawaii on oil as the principal source of energy for the state. Among other things, this directive included assessment of the technical and economic feasibility of increasing the contribution of renewable energy resources toward meeting the state's electrical generation and transportation fuel use. A series of six assessments were conducted pursuant to that mandate by the University of Hawaii's Economic Research Organization and Hawaii Natural Energy Institute; the U.S. Department of Energy's National Renewable Energy Laboratory; and FACTS Global Research—and the Secretary's report is under review. This paper is based on those assessments and that report. As directed by the legislation, the assessment of renewable energy potential was done on an island-by-island basis.



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

The State of Hawaii has already adopted numerous policies to promote renewable energy and fuels development. These include a renewable portfolio standard to produce 20% of state electricity from renewable energy sources by 2020, a 10% ethanol content requirement for gasoline, 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 production, and state and local fuel tax exemptions for ethanol and biodiesel. Hawaii has also recently initiated a major general effort to expand its use of renewable resources and reduce its dependence on oil in the form of the Hawaii Clean Energy Initiative (HCEI). The HCEI is a joint collaboration between the U.S. Department of Energy (DOE) and the State of Hawaii established through a memorandum of understanding signed in January 2008. 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 by up to 72%. With on-the-ground DOE support in Hawaii, DOE and Hawaii have already started to work collaboratively to stimulate advances in the areas of end-use efficiency, grid integration and storage, grid modeling, policy transformation, and biofuels production.

2. Oahu Electricity

With the highest population and relatively limited resources, Oahu is clearly the most challenging island for reducing oil dependence. The exception to the current lack of inter-island electrical-grid connection could be to serve Oahu. Developers have expressed interest in building a couple of major wind farms on other islands, intended for servicing Oahu by undersea cable.

Oahu is serviced by the Hawaiian Electric Company (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 (municipal solid waste) [1]. 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.

Although facing public acceptance or technical challenges, wind offers the highest potential for major renewable energy contribution to Oahu electrical needs. Best prospects are for reestablishing a wind farm at Kahuku on property now owned by the U.S. Army where a 12 MW project previously operated. A 40 MW project was previously proposed in the Kahe area, but was dropped in the face of strong public opposition. Private interests are reported to be interested in developing projects including up to

400 MW and 300 MW, respectively, on Lanai and on Molokai, each to deliver the power to Oahu by undersea cable.

Although the assessment found land for utility-scale solar-electric projects to be especially scarce on Oahu, some potential sites were identified. Additionally, there may be potential for significant commercial and residential rooftop PV development [2]. Solar power has a notable advantage on Oahu and in all of Hawaii, in that resource availability largely coincides with power use. Rooftop development would be PV plus solar thermal for domestic hot water. Utility-scale projects could also use more cost-competitive solar thermal technology. One former sugar plantation area was assessed as being capable of growing enough grass to support 7 MW of biomass electrical generation.

3. Hawaii Electricity

The Big Island of Hawaii is blessed with major renewable energy electrical generation resources. The current 270 MW capacity of the Hawaiian Electric Light Company, a subsidiary of the Oahu-based HECO, already includes up to nearly 80 MW from geothermal (30 MW), wind (33 MW), and hydroelectric (15 MW) sources.

Potential additional geothermal power development is estimated to be 750 MW, far more than the island's current use. This estimate excludes direct development of culturally and ecologically important forest reserves, but impact on the forest reserves would be an issue for any additional geothermal development, and previous proposed developments have aroused vigorous opposition.

Assessment identified additional potential renewable energy-generation capacity of 20 MW from hydroelectric facilities, 13 MW from municipal solid waste combustion, 11 MW from biomass combustion, and 10 MW or more from wind turbines. The high-potential wind sites are found in three areas, all of which already have some wind development, but any of which would require transmission system upgrades (normal practice for wind development, but time consuming and costly).

A number of possible sites for utility-scale solar energy development were identified. Also, potential for commercial and residential rooftop PV is high with one hotel having a 620 kW system and the local utility estimating that the Island of Hawaii likely has more PV systems per capita than any other U.S. location.

4. Maui Electricity

The Maui Electric Company (MECO) operates oil plants providing about 250 MW of base-load electric power for Maui. Another approximately 16 MW of base-load power is produced by the Hawaiian Commercial and Sugar Company in a biomass plant primarily using bagasse (sugarcane fiber), 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 [1]. This includes the largest wind farm in Hawaii, the 30 MW Kaheawa Pastures Project.

While not as large as that of Hawaii, Maui also has substantial identified geothermal power potential. Found in two zones, the total potential has been estimated at 140 MW. Together with wind potential and considering the current renewable electricity generation, Maui's total current electricity use could nearly be supplied from renewable sources.

Wind potential on Maui includes a single 40 MW Ulupalakua Ranch wind farm proposal and several other unquantified sites. Additonally, several potential utility-scale solar power project sites have been identified, including the Kahalui airport; the old airport at Puunene; and sites near the Kahalui power plant and Kiihei, an area with anticipated load growth. Potential areas for growth of trees or grasses were estimated as sufficient for 8 MW of biomass power generation, but could be as high as 33 MW.

5. Kauai Electricity

With substantially smaller population than Oahu, Hawaii, or Maui, Kauai's 2003 power use averaged 49 MW, 94% of that from imported fossil fuel. The current high oil dependency contrasts with the situation in the 1980s, when nearly half of the island's electricity was renewable, coming from biomass power based on bagasse residue from the island's sugarcane industry—which, subsequently, dramatically declined—and some hydroelectric power.

Although it has not yet developed any modern renewable energy projects, the island's utility (the Kauai Island Utility Cooperative) has been actively exploring the possibility. They have issued requests for proposals, pursued power purchase agreements, and sponsored a major "Renewable Energy Technology Assessment." [3] That 2005 assessment identified a mix of recommended wind (40 MW), hydroelectric (20 MW), biomass (20 MW), and municipal solid waste (7 MW) and other projects totaling nearly 100 MW, more than enough to meet the island's entire current electrical use.

Ranking wind as the most prominent near- and long-term renewable energy option, the 2005 assessment identified 40 MW potential at six sites. Some of this was near popular tourist areas, so careful siting and development of public support would be necessary, as would electrical grid enhancement.

Although not part of the recommended development package, the 2005 assessment identified two sites suitable for major utility-scale, solar power developments, one on the Barking Sands Pacific Missile Range Facility and one near Poipu, a major tourist area. At 285 MW on 730 acres, even at assumed 20% capacity factor, such an installation would be capable of producing more than the island's total current electrical use by itself. While PV would be expensive power, solar thermal projects can be quite cost-competitive.

6. Molokai Electricity

Molokai is part of Maui County and is serviced by MECO, which has approximately 12 MW [1] of diesel electricity generation capability for the island. Molokai experimented with wind power coupled to a diesel generator in the early 1990s, but that equipment is no longer operating.

Wind power is the most attractive renewable energy resource for Molokai, both for immediate local needs and for potential statewide contribution. One of the six assessments conducted in response to Section 355 of EPAct 2005 specifically analyzed the feasibility of using wind turbines to meet Molokai power needs. This assessment found that installation of four 1.5 MW turbines could cost-effectively meet half of Molokai's current power needs, returning life-cycle cost savings of 20%–40% [4]. As with any wind development in Hawaii, this would involve solving challenges related to integrating the wind power with the existing grid system. Exploratory discussions also have identified interest in building a wind farm on Molokai, producing up to 300 MW, most of which would be intended for transmission to Oahu by undersea cable [5].

Initial assessments also identified potential to grow enough biomass to fuel a 6 MW biomass plant and an area suitable for utility-scale solar power development. Together with the 6 MW of identified economically attractive wind power, this indicates it would be easily possible to meet all of Molokai's current power use with renewable energy.

7. Lanai Electricity

Like Molokai, Lanai is part of Maui County and is serviced by MECO, which has approximately 9.4 MW [1] of oil-based electricity generation capability for the island.

Also, like Molokai, Lanai's most promising renewable energy resource appears to be wind. To address Lanai demand, transmission would need to be built from the southwest part of the island, where one potential site has been identified [6]. Major Hawaii corporation Castle & Cook, Inc. is, however, reportedly considering a wind farm in the area that could generate up to 400 MW of power, most of which might be sent by undersea cable to Oahu, but could also serve Lanai demand [7].

Solar energy also was identified as a viable technical option for meeting Lanai's modest power use. 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 [8], and a planned 1.5 MW PV installation was recently announced [9]. Lower-cost solar thermal projects would presumably also be a possibility. Lower population density may also make rooftop PV applications, including off-grid, an attractive option.

8. Statewide Electricity

Thus there appears to be ample resources to make it technically feasible to significantly increase the contribution of renewable energy electricity generation for Hawaii. Indeed, identified resources are adequate to meet all of current use for each of the islands except Oahu. This, of course, does not say that the necessary developments would be economically viable or politically or socially acceptable. In fact, past proposals for geothermal power plants and wind farms—the biggest potential renewable energy contributions—have been dropped because of local opposition. Any development would be 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. All of these constraints should be considered given future prospects for (and net costs of) continued fossil fuel use.

Rooftop PV systems could potentially meet a significant portion of Oahu energy use. And increasing Oahu's renewable energy-based electricity with PV and other technologies may also leverage resources on other islands. Announced proposals to develop wind energy from Lanai and Molokai equal 40% of Oahu's current generating capacity. So, a combination of on-island and neighboring island development, could make major inroads.

The technologies discussed in this paper are all commercially available today. Given the current high price of electricity in Hawaii—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)[1]—they are also cost competitive in most cases. The following representative renewable energy cost ranges may be somewhat higher in Hawaii, but can be seen to compare quite favorably with the price of electricity in Hawaii.

- 5-8 ¢/kWh for wind,[2]
- 20-40 ¢/kWh for solar (PV),[3]
- 12-18 ¢/kWh for concentrating solar thermal power,[4]
- 4.5-17 ¢/kWh for biomass,[5]
- 3-12 ¢/kWh for municipal solid waste/landfill gas,[6]
- 4-7 ¢/kWh for geothermal,[7] and
- 4-7 ¢/kWh for hydroelectric.

Specific costs will vary in Hawaii, but given the current electricity pricing, government leadership, and public interest, developers have proposed a number of projects that they think will be both cost-effective and commercially viable. Note that the 287 MW_e of ground-mounted, utility-scale solar potential identified by the assessments represents opportunities that might be satisfied by either solar photovoltaic or concentrating solar thermal technologies.

Table 1 (at the end of this paper) summarizes statewide estimated renewable energy potential based on those assessments, with existing installed capacity given for comparison. The potential capacity from new renewable sources totals 2,133 MW, nearly the current installed capacity for the state (2,414 MW_e). Adding a statewide estimate of rooftop solar potential (see footnote 9) adds an additional net solar potential of more than 2,000 MW_e, nearly doubling the total.

Dramatically reconfiguring the electrical system on a statewide basis may allow for synergies among the islands not yet realized. For instance, analysis of statewide mapping of wind potential conducted by NREL as part of the EPAct effort suggested potential for 1,850 MW_e, more than

[1] Data from Energy Information Administration's Form EIA-861 for 2006 [9], the latest date for which data were available as of this writing. See http://www.eia.doe.gov/cneaf/electricity/page/eia861.html.

[2] Onshore siting, 1-3 MW, 60-100 meter blade diameter. See also Wiser and Bolinger 2007 [10].

[3] For low-latitude locations, assuming solar insolation of 2500 kWh/m^2/yr

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

[5] 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 [11]. 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* [12].

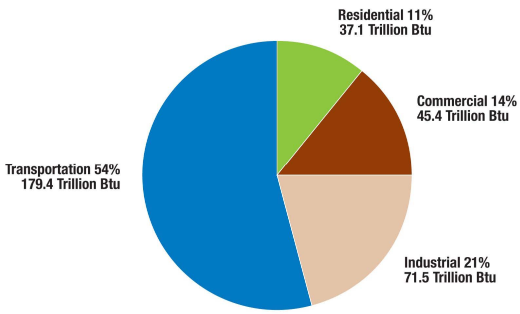
[6] For a 12 MW system (Advanced Energy Strategies 2004) [13]. A 1 MW landfill gas system is costed at ~3.7¢/kWh (2010 dollars) in Tiangco et al. 2005 [11].

[7] 1-100 MW binary, single- and double-flash, natural steam systems. From Martinot et al. (2007) [12]

twice what was identified by the specific site assessments.[8]

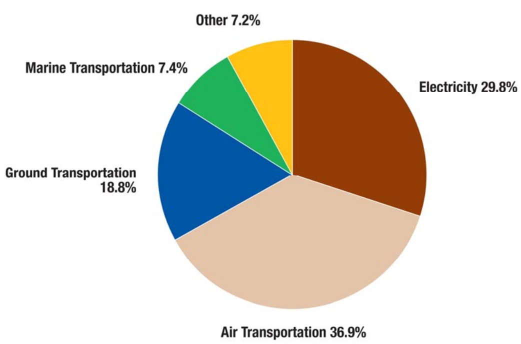
9. Transportation Fuels

At 180 Trillion Btu per year, the transportation sector consumed 54% of the State of Hawaii's energy demand (2005) and 63% of its petroleum demand (2003), as shown in Figures 2 and 3.



Source: EIA State Energy Data, 2005

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



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)

[8] A statewide Hawaiian wind potential for 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) [14].

With extensive former sugarcane land available, biomass fuels might be a natural way to address Hawaiian transportation fuel needs. To assess the potential for displacing petroleum use for transportation, as part of the EPAct assessment, the Hawaii Natural Energy Institute conducted a study titled "A Scenario for Accelerated Use of Renewable Resources for Transportation Fuels in Hawaii. [15]" This study examined prospects for meeting gasoline use with ethanol, primarily by assessing the amount of land potentially available for growing crops that could be processed to ethanol. The study looked at four crop scenarios and four categories of land.

The first crop scenario looked at potential for sugarcane production, a crop that was historically grown on large acreages of Hawaii and that can readily be converted to ethanol by fermentation of sugar with current commercial technology. A second crop scenario looked at potential production of fast-growing trees (leucaena and eucalyptus) on all soils suitable for growing trees. Note that the cellulosic conversion technology necessary to produce ethanol from woody biomass is still developing and not yet in full-scale commercial operation. A third crop scenario would grow cane on all lands suitable for it, and trees on any remaining land that is suitable for growing trees. The final crop scenario would grow banagrass on the same acreage identified as suitable for growing cane.

The most inclusive land category was all land zoned for agriculture and suitable for growing the particular crop. A slightly less-inclusive category was ALISH or "agricultural lands important to the State of Hawaii." These are lands for which the State of Hawaii will be developing incentive program to keep them in agricultural production. Other categories examined were lands owned by large landowners (about 70% of the total agricultural land) and government-owned agricultural land. The results for the assessment for these crop scenarios and land categories are summarized in Table 2 at the end of this paper.

Statewide, 2005 Hawaiian gasoline use totaled 454 million gallons. With its lower energy content, it would take 668 million gallons of ethanol to supply this use. Assessment identified statewide total potential fuel ethanol production from all agriculturally zoned land as 429 million gallons from 360,000 acres, if cultivated in sugarcane; 525 million gallons from cellulosic conversion of banagrass grown on the same acreage; 489 million gallons from cellulosic conversion of fast-growing trees from 699,000 acres suitable for tree farming; or a total of 705 million gallons from growth of sugarcane on all suitable acreage; and trees on 394,000 remaining acres suitable for tree farming. Thus, as for electrical generation, it would be possible to meet much of the Hawaiian gasoline market with renewable resources. Capture of more than 10% of the market would, however, also presuppose substantial purchase of flexible-fuel vehicles, currently only about 2% of the Hawaiian fleet.

Looking at the more-immediate-prospect sugarcane crop scenario on an island-by island basis, the assessment found that Kauai, Hawaii, and Maui (including Lanai and Molokai) counties could all potentially produce enough ethanol on ALISH lands alone (or just large-landowner land for Kauai and Maui) to displace their entire current gasoline use. On a statewide basis, enough cane could be grown to produce ethanol to displace 64%, 59%, and 47% of current gasoline use on all agricultural lands, ALISH lands, and large-landowner lands, respectively. Although precluding growth of dedicated biomass power on the same lands, ethanol production from sugarcane would also generate bagasse residue for biomass power generation.

Note that with current transportation technology, ethanol would still only meet a small portion of the total Hawaiian transportation fuel market. As shown in Figure 3, air transportation—which requires jet fuel (kerosene)—uses 37% of Hawaii's total energy consumption; marine transportation—which requires mostly diesel—uses 7% of Hawaii's total energy consumption; and the heavy truck and bus portion of the 19% of total energy use that is ground transportation would also require diesel.

Current Hawaiian diesel use for transportation totals about 200–250 million gallons per year. Current modest Hawaiian biodiesel production (700,000 gal/yr) is all based on used cooking or other waste oil and could only rise to about 2 to 2.5 million gallons in 2030. Although various tropical oil-seed crops might be suitable for Hawaii, there has been no significant experience with them, so no site-specific assessment was made for the potential of biodiesel production as part of the EPAct effort. An outside study, however, did estimate that with cultivation of dedicated oil crops, more than 160 million gallons of biodiesel could potentially be produced per year in Hawaii [16]. Any biodiesel oil seed production, however, would use the same land identified for ethanol production, which would also largely be the same land identified for biomass energy production for electrical production. These three potential renewable energy contributions are not additive and tradeoffs among them would be necessary if more than one is pursued.

A potential technology not quantified by the assessment that could be particularly appropriate for Hawaii is oil production by microscopic algae. Both the National Renewable Energy Laboratory and the University of Hawaii have been key players in development of this technology. While microalgal oil was previously examined primarily for biodiesel production, a key factor in its current resurgence is that oil refiners have now determined that it would be an appropriate feedstock for hydrocracking, a standard refinery process for producing specific products. Thus microalgal oil could be converted to jet fuel, addressing perhaps the biggest fossil fuel energy challenge facing Hawaii.

Potential new transportation technologies such as electric or fuel-cell vehicles could also be highly appropriate for Hawaii, with its inherently short, typical daily driving distances. Once either become widely available, the development of large potential electrical projects such as geothermal on Hawaii, solar thermal on Kauai, and wind on Molokai or Lanai would become more attractive as excess capacity could be used for charging batteries or electrolyzing hydrogen. Hydrogen technology development generally could also offer important opportunities for Hawaii and reducing its dependence on imported oil.

10. Conclusion

The State of Hawaii is highly dependent on imported oil for all its energy needs—electrical generation as well as transportation fuel. As identified by assessments conducted in response to directive of Section 335 of the Energy Policy Act of 2005, however, it also has extensive renewable energy resources that could reduce that dependency substantially. All of the islands other than Oahu could potentially meet their total electrical needs with cost-competitive renewable energy projects. Some of these geothermal, wind, and other projects have aroused intense opposition in the past, however, so local political choice may be as big a factor as the economic and technical viability of the projects. Although Oahu does not have adequate identified potential renewable energy resource projects of its own to be self-sufficient, undersea cable transmission from development of wind farms on nearby islands could meet a substantial portion of its electrical use. Former sugarcane fields and other agricultural lands could be used to grow energy crops sufficient to produce ethanol equivalent to as much as 60% of Hawaii's current gasoline use. Alternatively, some or all of these lands could grow oil seeds for biodiesel production, but those oil seed crops have not yet been well-evaluated in Hawaii. No immediate alternative source has yet been identified for Hawaii's quite extensive use of jet fuel.

Acknowledgments

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General note — This paper is based on the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy's "Assessment of Dependence of State of Hawaii on Oil," report prepared as directed by Section 355 (c) of the Energy Policy Act of 2005. That report was based on the following six reports, also prepared pursuant to Section 355 and all available at www.eere-pmc.energy.gov/hawaii.aspx. Any data or assertion not otherwise cited comes from those reports.

- "Current State of Hawaii's Energy Resources and Utilization," by Terry Surles and Milton Staackmann (Hawaii Natural Energy Institute)
- "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)
- "Relationship of Refinery Operations and Oil-Fired Generation," by Terry Surles (based on material developed by FACTS, Inc. in report No. 5)
- "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)
- "Evaluating Natural Gas Options for the State of Hawaii," FACTS, Inc.
- "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).

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Table 1. Summary of Estimated Hawaiian Renewable Energy New Technical Potential (in MW_e) (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[9]]	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 [63]	287 (2,287 [10]) [0.62]	52 [16]	21 [45]	890 [30]	43 [15]	2,133 (4,133[11]) [~170]
NET NEW POTENTIAL FROM ALL SOURCES: ~ 2133 MW_e (~4,133 MW_e); NET INSTALLED ~170 MW_e							

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

[10] 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 [17]. 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.

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

Table 2. Summary Table of Statewide Ethanol Potential for Four Land Groupings and Four Crop Scenarios[12]

	Total Potential, Zoned Ag	Zoned Ag, State Owned	Zoned Ag, Large Land Owners	Agricultural Lands Important to the State of Hawaii
1) Sugarcane				
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) Sugarcane 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

[12] 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.