RENEWABLE ENERGY TECNOLOGY ASSESSMENTS

Final Report

March 2005

Prepared for

Kaua`i Island Utility Cooperative

Your Touchstone Energy® Cooperative

Black & Veatch Project
137174

building a world of difference™

BLACK & VEATCH

Kaua`i Island
Utility Cooperative
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Renewable Energy Technology Assessments

FINAL REPORT
B&V Project Number 137174

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1.0 Executive Summary

The objective of this study is to identify the best options for renewable energy development on the island of Kauai. Kauai Island Utility Cooperative (KIUC) has retained Black & Veatch to undertake this assessment of renewable energy technologies and potential projects. This summary provides a comprehensive overview of this Final Report.

1.1 Introduction

In 2003, over 94 percent of Kauai's electricity was generated from imported fossil fuels – the highest level of fossil fuel dependence in over 25 years. This coincides with a period of record oil prices, political and military strife, and concerns about impacts on the global environment from increased consumption of fossil fuels. At the same time, Kauai is blessed with rich indigenous resources and historical experience using renewable energy sources to meet a large share of its energy needs.

This study examines a return to renewable energy resources as part of KIUC's upcoming Integrated Resource Plan (IRP) filing. In addition, KIUC anticipates utilizing the results of this study to develop a strategy to meet the renewable portfolio standard (RPS) established by the Hawaiian legislature. This standard calls for 20 percent of electricity to be generated from renewable sources by 2020. Accounting for solar water heating, KIUC sourced 7.5 percent of its energy from renewable resources in 2003. While on pace for the 2020 goal, Kauai's reliance on renewable resources has steadily been declining. In the early 1980s, hydro and biomass accounted for upwards of 40 to 50 percent of electricity generated on the island. This energy came largely from sugar mills. As the sugar industry has declined, so has Kauai's primary source of renewable energy.

This study is being undertaken in two phases. This Final Report is a comprehensive account of both. An Interim Report covered Phase 1, describing the existing use of renewable energy on the island, generation technology options, and the developable potential of the different resources. The Interim Report reviewed a broad range of renewable energy technologies and concluded with the scoring of the technology options and recommendations for further study in Phase 2. Phase 2 of the project characterizes the most promising options in greater detail and identifies specific projects for possible implementation.

1.2 Renewable Technology Options

Twenty six renewable and advanced energy technologies were assessed in Phase 1. The technologies were split into ten categories as follows:

1. Solid biomass (p. 3-3)
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(Page references for the technology screening section are shown in parentheses. The five technologies carried forward for detailed analysis are underlined.)

Generally, each technology was described with respect to its principles of operation, applications, resource characteristics, cost and performance, environmental impacts, and outlook for Kauai. The outlook for Kauai included an assessment of the potential developable resource within the next 3, 5, 10 and 20 years.

1.3 Renewable Energy Technology Screening

A technology screening methodology was used to evaluate, rank and select Kauai renewable energy resources for further investigation. The assessment methodology employs a set of seven weighted criteria:

- Cost of energy (50 percent)
- Kauai resource potential (10 percent)
- Fit to KIUC needs (10 percent)
- Technology maturity (10 percent)
- Environmental impact (7.5 percent)

- Socioeconomic impact (7.5 percent)
- Incentives/Barriers (5 percent)

Cost of energy accounts for 50 percent of the overall screening score, with the rest of the criteria contributing varying degrees to the remaining 50 percent. As some of the scores will change over time as a technology matures or KIUC's needs change, screening of technologies was done at intervals of 3, 5, 10 and 20 years in the future. Highlights of the screening include the cost of energy (Figure 1-1) and Kauai resource potential (Figure 1-2).

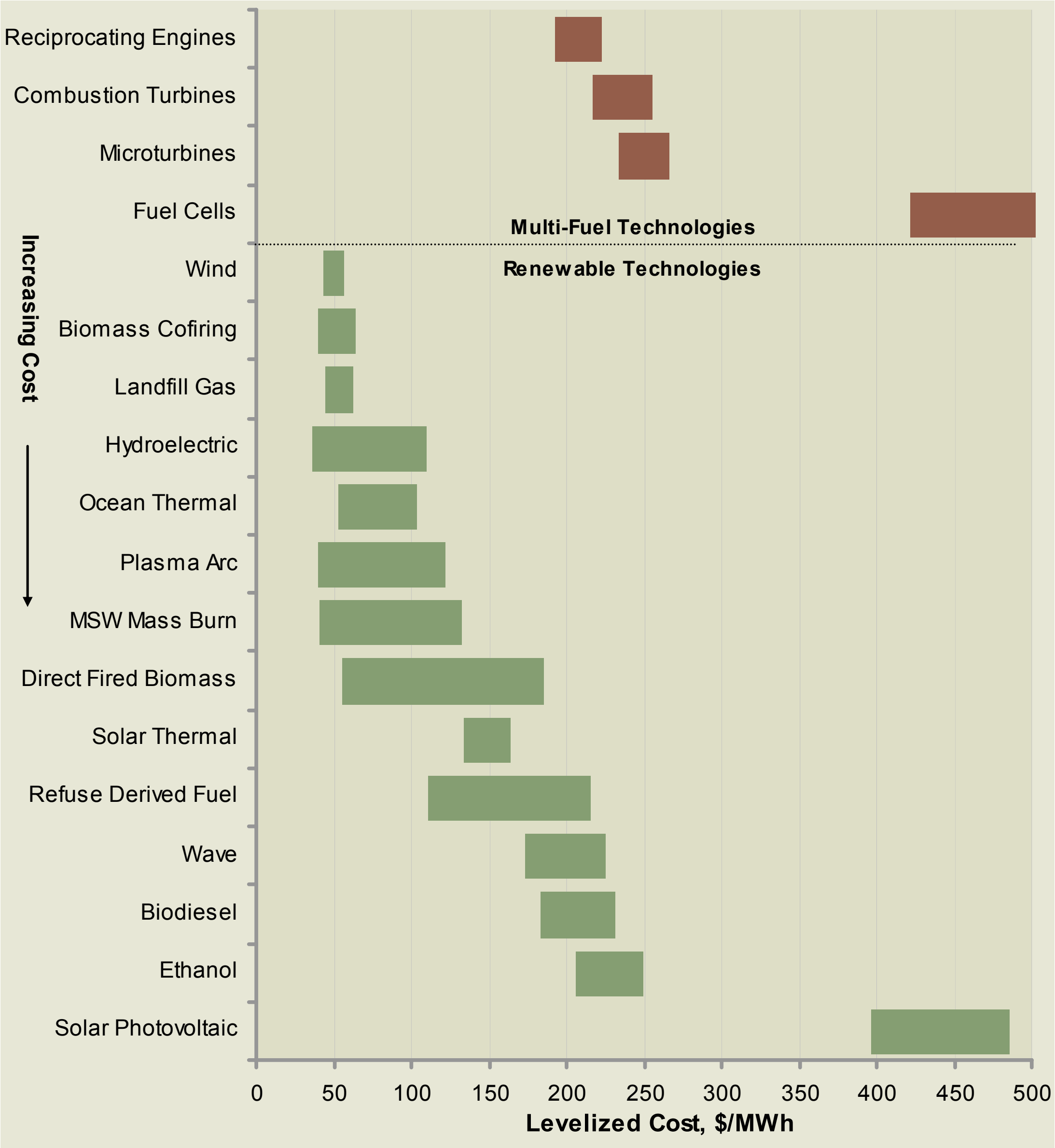

Figure 1-1. Range of Levelized Cost for Renewable Technologies (Three Year Timeframe).

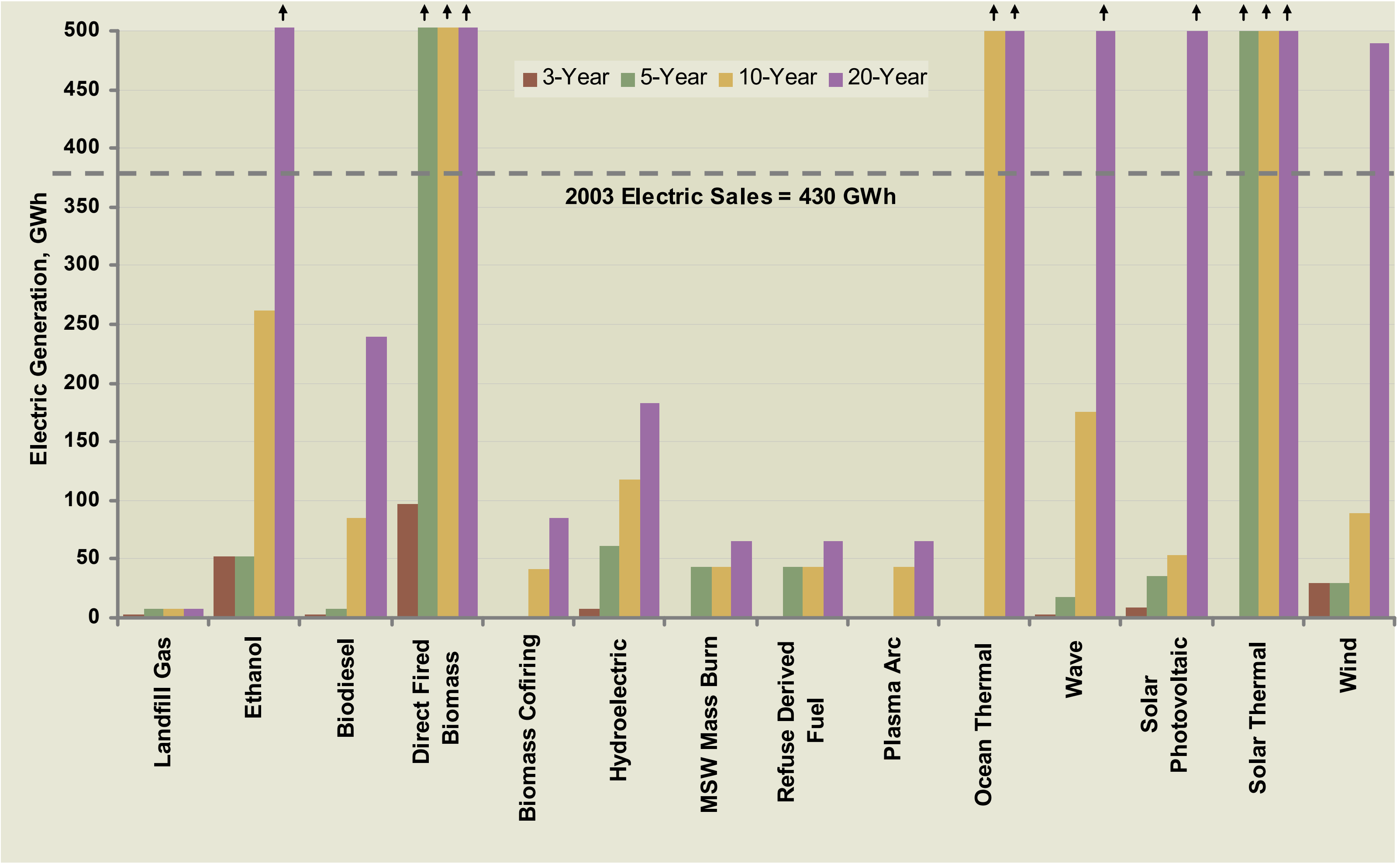

Figure 1-2. Developable Potential of Kauai Renewable Resources (Annual Generation, GWh/yr).

The cost of energy results demonstrate that there are numerous technologies with generation costs below $100/MWh (10 cents/kWh), which is lower than KIUC's current avoided energy cost. Low cost options include wind, biomass cofiring, hydro, municipal solid waste (MSW), and landfill gas.

The Kauai resource potential results demonstrate that in addition to there being numerous low cost power options, renewable resources are abundant on Kauai. There are several resources that could theoretically meet all of Kauai's electrical energy needs, which totaled about 430 GWh in 2003. These include direct fired biomass and solar thermal in the near term, and in the long term, ethanol, ocean thermal, ocean wave, solar photovoltaic, and wind. Biodiesel and hydroelectric also have good potential.

The cost of energy and resource potential criteria were combined with the other measures and applied over 3, 5, 10 and 20 years. The results for each period are shown in Figure 1-3. In general, the scores trend upward over the 20 year evaluation period. The reasons for this are improvements in cost of electricity, developable resource, and technology maturity. Based on the results of the screening analysis, Black & Veatch recommended that landfill gas, wind, hydro, direct fired biomass, and MSW mass burn be examined in Phase 2. KIUC concurred with this recommendation.

Following a discussion of renewable energy financial incentives, the remainder of this section summarizes the project assessments performed for these five technologies. Selected project locations are shown in Figure 1-4.

1.4 Renewable Energy Financial Incentives

A number of state and federal renewable energy development incentives were examined for applicability to KIUC and the types of projects analyzed in Phase 2. There are two basic types of incentives, tax related and non-tax related, such as grants and green pricing programs. The primary means by which the federal government has supported the development of renewable energy is through the production tax credit (PTC), reduced depreciation life, and the renewable energy production incentive (REPI). After a recent expansion, the PTC now provides $18/MWh (inflation adjusted) for wind, solar, geothermal, and closed loop biomass. The PTC is also available at $9/MWh for open-loop biomass, small hydro, and municipal waste. Wind and closed-loop biomass receive PTC for 10 years, other technologies receive credit for 5 years. The reduced depreciation life incentive allows taxable entities to depreciate some renewable energy equipment over a period of five years. REPI provides for payments of about $18/MWh to public utilities and governmental entities for the production of renewable energy; however, this credit expired at the end of 2003.

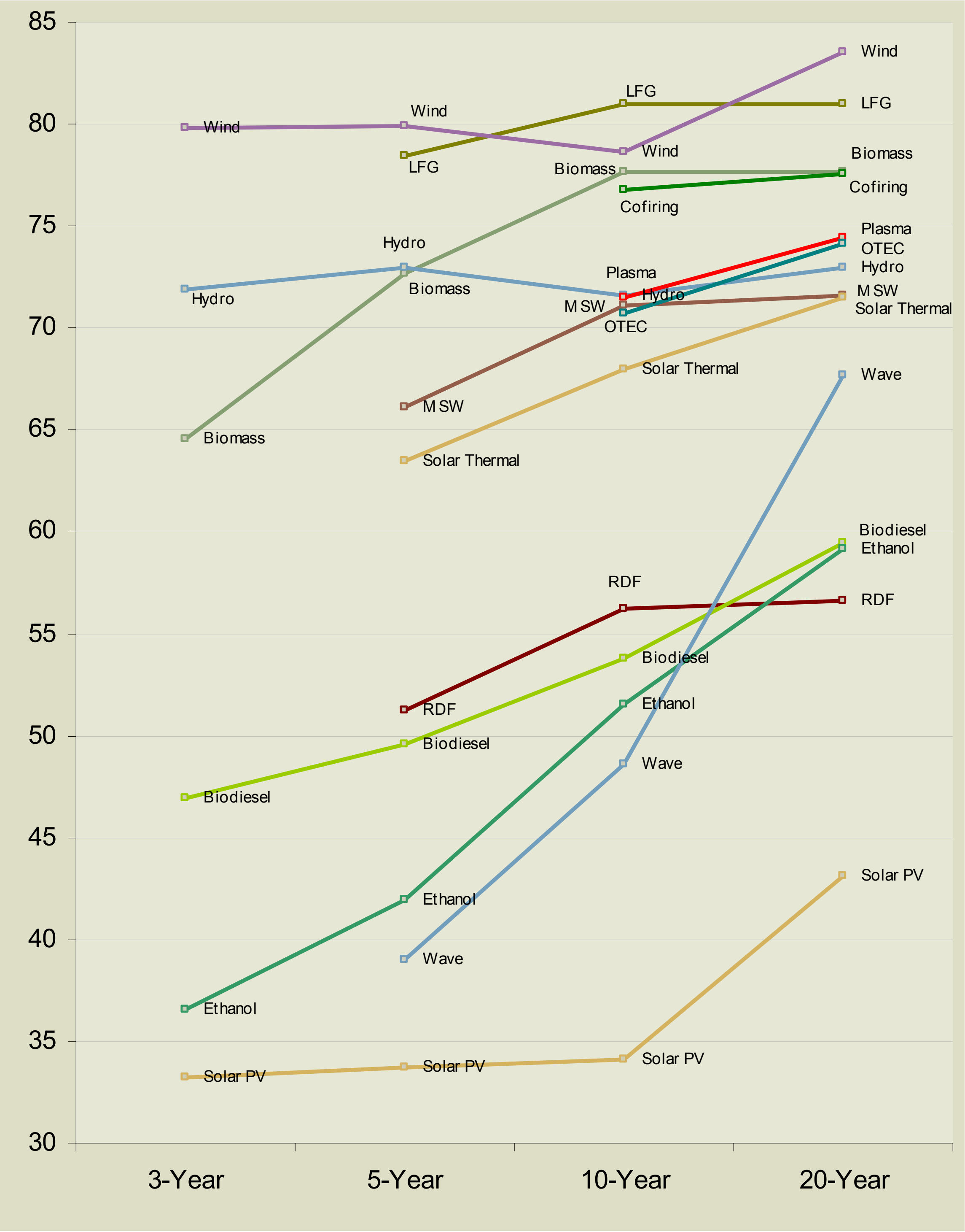

Figure 1-3. Change in Technology Screening Scores by Timeframe (max=100).

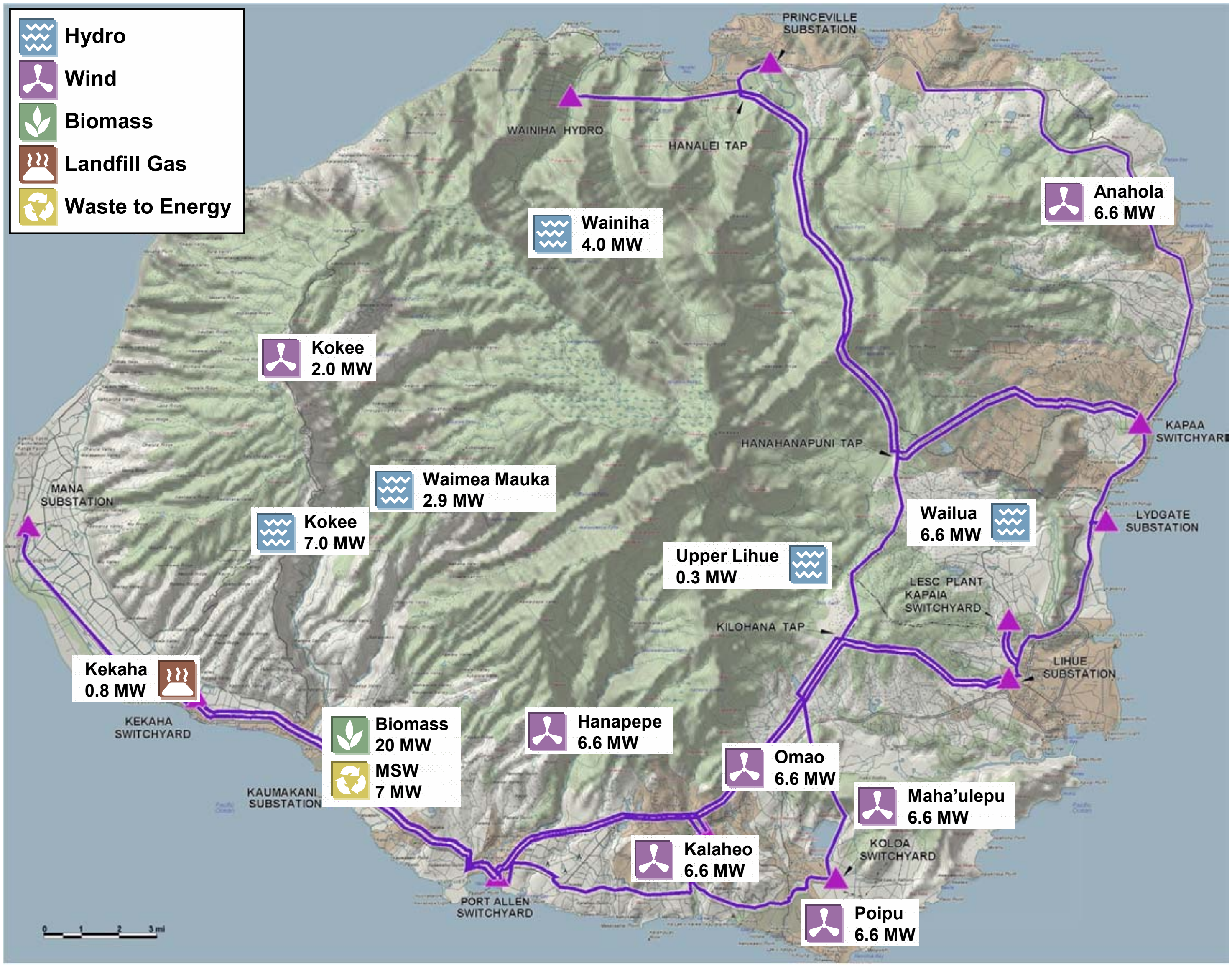

Figure 1-4. Selected Project Locations.

The production tax credit is an attractive incentive that applies to most of the projects profiled in detail in this report. Although the federal tax incentives typically are only available to taxable entities, there are project structures which may allow KIUC to partner with private entities. In this manner, KIUC could finance the project with its low cost financing, while the taxable entity could take advantage of the value of the tax credits. Further financial and legal review would be required by KIUC, but if tax credits continue to be offered for the next five to eight years, this ownership structure could be an interesting option for KIUC to consider.

Various grants offered by the federal government and available to public utilities and governmental entities were also identified. With residential rates at about triple the national average, KIUC would qualify for the USDA High Energy Cost Program. KIUC could also receive funding under provisions of the 2002 Farm Bill supporting renewable energy development. Additionally, from time to time grants are also available from the Department of Energy and other agencies for development and demonstration projects. Any of these programs could potentially provide in excess of $1 million towards the development of a project. These grants are offered to provide assistance for areas with high electric rates, tribal economic development, renewable technology demonstration, and various other policy or technology objectives. Funding for these grant programs can change significantly from year to year, and policy objectives of the organizations that offer grants change over time; therefore, it is difficult to predict the amount of funds available from a particular program for a particular project. In any case, before project development activities proceed, opportunities for grant funding should be identified and pursued.

Green pricing and renewable energy credits may be viable methods for KIUC to capture additional value from renewable generation. Utility green pricing programs allow customers that want more renewable energy to pay a small premium on monthly electricity bills to support renewable development. Renewable energy credits are tradable credits that represent the "green attributes" of renewable energy. These credits can be sold to voluntary purchasers (such as the federal government) or used to meet mandatory targets established by renewable portfolio standards. If KIUC has excess renewable energy, it might be able to sell excess credits to other Hawaiian utilities.

The remainder of this executive summary reviews key findings for the five technologies which passed the Phase 1 screening. Economic analysis is performed assuming all projects come online in 2009.

1.5 Biomass and Municipal Solid Waste

Biomass project sizes from 5 to 30 MW were considered, and an optimum size of 20 MW was selected based on preliminary technical and economic analysis. The biomass fuel mix and cost change based on the project size. Smaller projects can utilize lower cost waste biomass resources (wood chips, bagasse, and cane trash), while larger projects would need to rely on dedicated energy crops such as banagrass (elephant grass). A stoker boiler was selected as the basis for the project conceptual design due to its good mix of technical maturity, efficiency, and cost. The location for the biomass project has not been specified yet.

After selecting 20 MW as the preferred size for the biomass project, capital and O&M costs and plant performance were estimated to determine cost of energy for such a plant for KIUC. The life-cycle costs were analyzed using the likely low, high and mid range fuel costs to establish upper and lower bounds for the analysis. The results of these estimates are shown in Table 1-1.

Table 1-1. Biomass Life-Cycle Economic Assumptions ($2005).

	Unit	Low Fuel Cost	Mid Fuel Cost	High Fuel Cost
Capacity	MW	20.0	20.0	20.0
Capital Cost	$/kW	4,556	4,556	4,556
First Year Fixed O&M	$/kW-yr	150	150	150
First Year Variable O&M	$/MWh	8.4	8.4	8.4
First Year Fuel Cost	$/MBtu	3.50	4.15	4.57
Net Plant Heat Rate	Btu/kWh	15,397	15,397	15,397
Capacity Factor	percent	80%	80%	80%
KIUC Levelized Cost	2009$/MWh	179.5	194.8	204.6
KIUC Premium*	2009$/MWh	5.6	20.9	30.7

*Electricity cost premium (or savings) compared to KIUC's forecasted avoided costs.

Based on the assumptions shown in Table 1-1, the levelized cost of electricity can be calculated. The levelized electricity cost includes all costs to generate power (capital, O&M, fuel, etc.) levelized over the life cycle of the project. In 2009, it is projected that the levelized cost of supplying power from a biomass fueled power station would range from $180/MWh to $205/MWh, depending on the fuel cost. This cost can be compared to the cost of KIUC's existing resources and projected new unit additions. These costs would be "avoided" if the biomass plant were built. Based on avoided cost forecasts from KIUC, biomass is able to avoid $174/MWh in energy and capacity costs on a levelized basis (2009$). Taking these costs into account, the premium for biomass ranges from \$5.6/MWh to \$31/MWh over avoided costs. The biomass power station does not compare favorably with the forecasted avoided costs because the fuel is expensive, the plant is relatively inefficient, and the capital costs are high.

The levelized cost for biomass is higher than the range predicted in the first phase of the report (up to \$186/MWh, see Table 3-1). The technology screening was done at a high level resulted in very broad, generic estimates of cost. As biomass was investigated in more detail, there were several changes that drove up the estimated cost of the facility. These include examining a smaller size, adding capability to burn multiple fuels, higher fixed O&M costs (largely labor), slightly poorer efficiency, and other factors. These factors combined to raise the price range of biomass outside of initial expectations.

Various technology options for waste to energy were compared in the screening section of the report, and it was determined that mass burn was the preferred conversion technology. Similar to biomass, no specific project size was identified for analysis, so the screening phase focused on selecting an appropriate size for the plant. A screening level analysis compared the cost of energy for various sized plants at the current (\$56/ton) and possible future (\$90/ton) tipping fee. Two project sizes, 200 and 300 tons per day, were evaluated. Due to economies of scale, it was determined that the 300 ton per day facility was the better choice economically, even if it had to purchase 100 tons per day of higher cost biomass to supplement the 200 tons per day of waste.

After selecting 300 tons per day (7.3 MW) as the preferred size for the MSW project, capital and O&M costs and plant performance were estimated to determine cost of energy for such a plant for KIUC. The life-cycle costs analyzed using the likely low, high and mid range fuel costs to establish upper and lower bounds for the analysis. The results of these estimates are shown in Table 1-2.

Table 1-2. MSW Life-Cycle Economic Assumptions (\$2005).

	Unit	\$56/ton Tipping Fee	\$70/ton Tipping Fee	\$90/ton Tipping Fee
Capacity	MW	7.3	7.3	7.3
Capital Cost	\$/kW	11,343	11,343	11,343
First Year Fixed O&M	\$/kW-yr	286.0	286.0	286.0
First Year Variable O&M	\$/MWh	23.1	23.1	23.1
First Year Fuel Cost	\$/MBtu	(5.09)	(6.36)	(8.18)
Net Plant Heat Rate	Btu/kWh	18,744	18,744	18,744
Capacity Factor	percent	70%	70%	70%
KIUC Levelized Cost	2009\$/MWh	108.66	72.38	20.39
KIUC Premium	2009\$/MWh	(68.00)	(104.28)	(156.27)

The range of tipping fees was selected to account for the current tipping fees at the Kekaha landfill (low), and estimated costs of disposal at a new landfill (high). The table shows that the relatively high cost of constructing and operating a waste-to-energy facility is compensated for by the high tipping fees paid to the plant to accept waste. The levelized cost of energy generation with KIUC ownership ranged from a very low $20/MWh to $109/MWh, depending on tipping fee assumptions. Compared to KIUC's forecasted avoided costs, the cost premium ranged from ($156)/MWh to ($68)/MWh. Assuming the $90/ton tipping fee is available, the MSW plant has the best economics of any of the alternatives studied in this project.

In addition to standalone biomass and MSW, a plant that combines both fuels was considered. Different equipment configurations were evaluated and a preferred approach and size characterized. For further information, please refer to Section 7 of the report. The economics of such a plant are between the standalone biomass and MSW options.

1.6 Hydro

Previous assessments identifying potential hydro projects on Kauai were reviewed and 49 possible project sites were cataloged. From this list, six promising projects were selected and characterized. The projects are located throughout the island and consist of four new sites and two upgrades of existing facilities. All the sites are run-of-river or run-of-ditch, which minimizes potential negative environmental impacts. The projects are summarized in Table 1-3.

The variability in project site requirements for hydro leads to broad ranges of potential costs. For hydropower projects, much of the cost is often off-site from the power plant in the diversion structures, penstock, and their associated access roads. For this reason, it is difficult to develop generic estimates of project costs without detailed site studies, and estimates from past studies, despite their age, are preferred. On this basis, capital and O&M costs were developed, as shown in Table 1-4.

Table 1-3. Selected Hydro Projects.

No.	Project Name	Status	Type	Static Head (ft)	Design Flow (cfs)	Plant Size (kW)		
						Exist.	Prop.	Total
1	Wainiha	new	run-of-river	433	139	0	4,000	4,000
2	Upper Lihue	upgrade	run-of-river	247	32	500	300	800
3	Wailua	new	run-of-river	262	150	0	6,600	6,600
4	Waimea Mauka	upgrade	run-of-river	265	55	1,000	2,900	3,900
5A	Puu Lua-Kitao	new	run-of-ditch	1,145	40	0	2,970	2,970
5B	Kitano-Waimea	new	run-of-ditch	2,093	30	0	4,078	4,078

Table 1-4. Hydro Life-Cycle Economic Assumptions ($2005).

	Unit	Wainiha	Upper Lihue	Wailua	Waimea Mauka	Puu Lua-Kitano	Kitano-Waimea
Capacity	MW	4	0.3	6.6	2.9	2.97	4.078
Capital Cost	$/kW	4,496	7,248	2,044	1,213	5,933	3,955
First Year Fixed O&M	$/kW-yr	67.5	101.8	31.1	27.7	89.6	61.6
First Year Variable O&M	$/MWh	N/A	N/A	N/A	N/A	N/A	N/A
First Year Fuel Cost	$/MBtu	N/A	N/A	N/A	N/A	N/A	N/A
Net Plant Heat Rate	Btu/kWh	N/A	N/A	N/A	N/A	N/A	N/A
Capacity Factor	percent	64%	69%	28%	15%	61%	48%
KIUC Levelized Cost	2009$/ MWh	58.4	86.1	60.4	79.1	81.8	69.9
KIUC Premium	2009$/ MWh	(116.3)	(88.6)	(114.4)	(95.7)	(93.0)	(104.8)

The levelized cost of generating power from the six projects ranged from $58/MWh for Wainiha to $86/MWh for Upper Lihue assuming KIUC ownership. Compared to KIUC's forecasted avoided energy costs, the levelized cost premiums ranged from ($116)/MWh to ($89)/MWh. The negative premium indicates that developing these resources is less expensive than the forecasts of KIUC's avoided costs. The best project appears to be the Wainiha project, which had undergone extensive development in the 1980s before being halted due to low power prices. It is noted that more than the other technologies, KIUC ownership of hydro projects many not be feasible in all situations. KIUC will need to work closely with other parties to ensure the most appropriate arrangement.

1.7 Wind

Using the preliminary wind resource map of Kauai as a guide, eleven areas for potential wind projects were identified. Each was examined in light of its location, wind resource and other factors as discussed with KIUC. The locations were rated as high, moderate, or low priority for continued development, as shown in Table 1-5. Seven areas were ranked as having a high or moderate priority and were studied in further detail using the validated wind map, available on-site wind data, Black & Veatch cost data, and other resources.

Table 1-5. Project Option Screening.

Area	Construct-ability	Trans-mission Access	Potential MW	Wind Class	Capacity Factor	Suitable for Dist. Project?	Priority
1: Kalaheo	good	good	100+	4-5	35%	yes	high
2: Omao	fair	good	15-55	5-6	34-40%	yes	moderate
3: Waialeale	bad	bad	100+	6-7	40%+	no	low
4: Kuahua	bad	bad	50	5-7	35-40%	no	low
5: Hanapepe	fair	fair	100+	5-7	36%	no	moderate
6: Kokee	good	fair	15	5-6	35-38%	yes	moderate
7: Kalalau	bad	bad	100+	6-7	40%+	no	low
8: Anahola	fair	fair	25	4-6	34%	yes	high
9: Poipu	good	good	100+	3-5	30-33%	yes	moderate
10: Maha'ulepu	fair	good	10-100	5-6	34-40%	no	moderate
11: Offshore	bad	bad	100+	6	40%+	no	low

In general, abundant wind potential was found on Kauai, and several likely project sites were identified. It is not expected that resource availability would limit the amount of wind power that could be developed. Rather, the amount of wind generation that could be integrated with the utility grid would be the limiting factor. Key factors for selecting a site to develop include visual impact, community support, and constructability.

Table 1-6 provides a summary of the wind project performance and economic assumptions as well as the results of the life-cycle cost analysis.

Table 1-6. Wind Life-Cycle Economic Assumptions ($2005).

	Unit	Kalaheo	Omao	Hana-pepe	Kokee	Anahola	Poipu	Maha'-ulepu
Capacity	MW	6.6	6.6	6.6	1.98	6.6	6.6	6.6
Capital Cost	$/kW	1628	1689	1947	2249	1826	1628	1689
First Year Fixed O&M	$/kW-yr	39.06	39.11	39.11	75.1	39.11	39.06	39.11
First Year Variable O&M	$/MWh	1.73	1.68	1.68	1.73	1.78	1.95	1.68
First Year Fuel Cost	$/MBtu	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Net Plant Heat Rate	Btu/kWh	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Capacity Factor	percent	35%	36%	36%	36%	34%	31%	36%
KIUC Levelized Cost	2009$/ MWh	64.46	64.24	70.76	95.88	71.68	72.77	64.24
KIUC Premium	2009$/ MWh	(90.10)	(90.32)	(83.80)	(58.68)	(82.88)	(81.79)	(90.32)

The levelized cost of generating power from the seven wind projects with KIUC ownership ranged from $64/MWh to $73/MWh for the 6.6 MW projects to $96/MWh for the 2 MW project. No wind site stands out as being vastly superior to others. This gives KIUC good flexibility (and negotiation position) in siting the first projects in the location deemed most suitable. When the avoided capacity and energy costs were considered, the levelized cost premiums ranged from ($90)/MWh to ($59)/MWh. These results indicate that wind is attractive economically compared to KIUC's forecast of avoided costs.

1.8 Landfill Gas

Although the landfill at Kekaha does not currently have gas collection facilities, a landfill gas (LFG) project was studied to estimate the capacity that could be expected from the landfill. The gas production and corresponding power generation were estimated for a landfill closure date of 2009.

Data from the landfill suggests that the methane content of the LFG would be approximately 40 percent. The maximum LFG flow was estimated to be 465 cfm in 2009 with the production declining to 345 cfm in 2024. An 800 kW capacity LFG plant was considered appropriate for the resource.

A Caterpillar G3516 natural gas engine was used to estimate project capital and O&M costs and plant performance to determine cost of energy. The results of these life-cycle cost estimates and the resulting analysis are shown in Table 1-7.

Table 1-7. Landfill Gas Life-Cycle Economic Assumptions ($2005).

	Unit	Kekaha Landfill
Capacity	MW	0.8
Capital Cost	$/kW	3,965
First Year Fixed O&M	$/kW-yr	111
First Year Variable O&M	$/MWh	16
First Year Fuel Cost	$/MBtu	-
Net Plant Heat Rate	Btu/kWh	11,491
Capacity Factor	percent	86%
KIUC Levelized Cost	2009$/MWh	98.83
KIUC Premium	2009$/MWh	(61.54)

The levelized cost of the landfill gas project was calculated to be about $99/MWh, with a premium of about ($62)/MWh. The favorable economics of the landfill gas project relative to forecasted avoided costs are due, in part, to the free fuel and the high capacity factor.

1.9 Final Renewable Energy Project Scoring

Based on the project characterizations form the previous section, the projects were scored with a scoring methodology similar to the technology screening in the Phase 1 analysis. The assessment methodology included the following weighted criteria:

- Levelized cost premium (50 percent)
- Kauai resource potential (10 percent)
- Fit to KIUC needs (10 percent)
- Technology maturity (10 percent)
- Environmental impact (7.5 percent)
- Socioeconomic impact (7.5 percent)
- Incentives/Barriers (5 percent)

The evaluation criteria were slightly modified from the initial analysis to better account for conditions affecting specific projects rather than general technologies. The most significant change is the measurement of projects by the levelized cost premium rather than the cost of energy. The levelized cost premium is equal to the levelized cost of energy less KIUC's forecasted avoided capacity and energy costs.

The levelized cost premium scoring revealed that nearly all of the proposed projects could be developed at a negative price premium (savings) relative to the forecasted avoided costs. Stated clearly, almost all the projects appear to be economically attractive. Figure 1-5 is a supply curve of the renewable energy options available to KIUC. The curve shows the amount of generation available from each technology plotted against the levelized cost premium in ascending order. The lowest cost options (left side of chart) were revealed to be hydro and wind projects. The base case fuel prices are used for biomass and MSW options. An important conclusion from the supply curve is that about 400 GWh of renewable energy projects were identified by this study at a cost below KIUC's forecasted avoided costs. KIUC generated about 430 GWh in 2003, largely from fossil fuel resources.

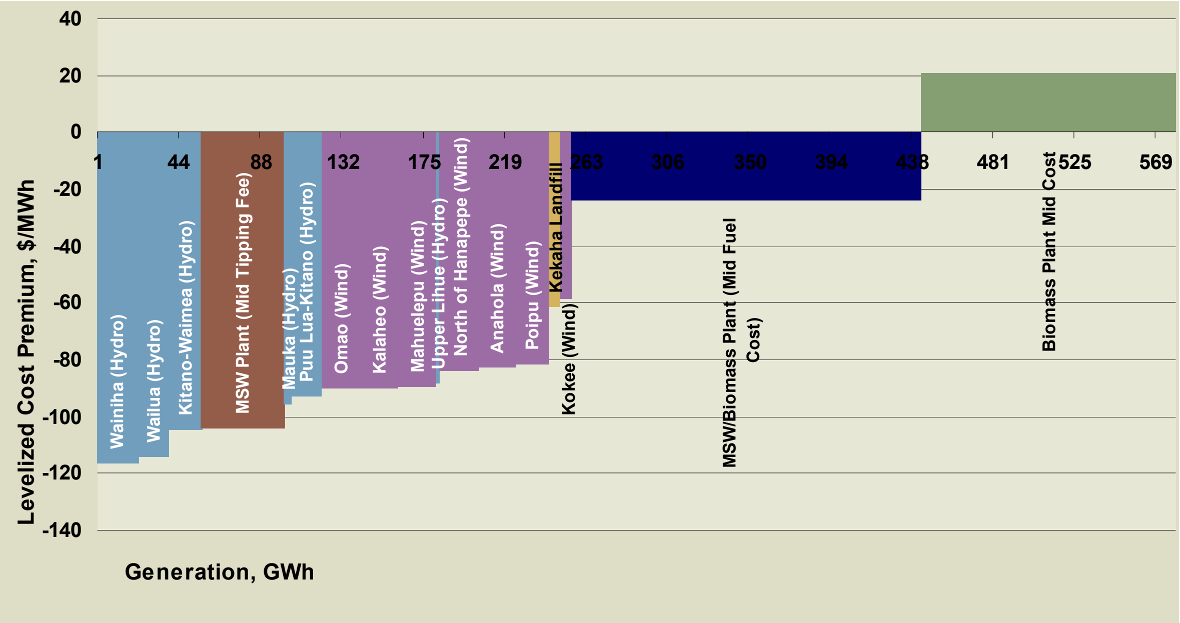

Figure 1-5. Levelized Cost Premium Supply Curve.

The scores of the initial screening for resource potential were reused for the project analysis. These scores served as a measure of the replicability of a given project type over the next 20 years. For example, there is limited MSW resource on the island, but large wind resources.

The fit to KIUC needs category provided a measure of the applicability and suitability of a given project for KIUC. Projects receiving the highest scores were generally small in capacity and provided more energy than capacity to the system. This is because the KIUC system is "capacity rich" in the short term. The projects scoring highest in this category included the hydro and wind projects.

The level of environmental impact was scored for each project. There was a significant difference between the environmental impacts from projects even of the same technology. For example, the Upper Lihue hydro upgrade project has practical zero negative environmental impacts, whereas the Wailua hydro project has significant environmental impacts because it requires development of a new reosource.

The scores from the preceding categories were combined with the technology maturity, socioeconomic impact, and incentives/barriers scores to produce the final score for each project. Figure 1-6 shows the breakdown of the final scoring results. Hydro and wind projects were generally the highest scoring types of projects due to their relatively low cost, high suitability for KIUC, and minimal environmental impact. While the MSW and biomass projects offer considerable socioeconomic benefits, the cost and unsuitability for KIUC in the near-term caused these projects be scored lower. The exception is an MSW plant with a high tipping fee. The economics of such a project are very attractive and cause it to score highest of all projects evaluated. The economic viability of the project is dependent on high revenue from tipping fees, which may not be practicable.

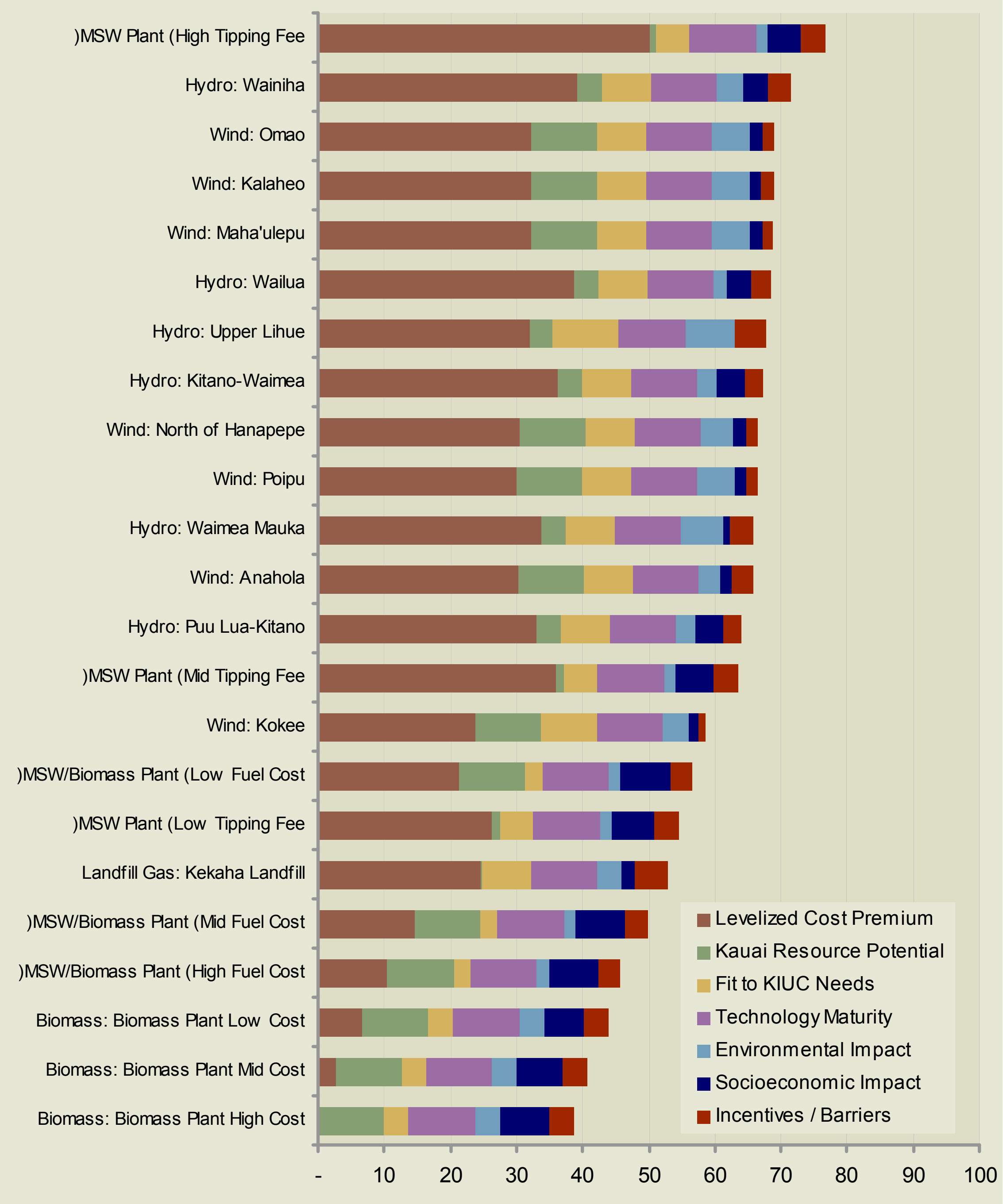

Figure 1-6. Scoring Results Breakdown.

1.10 Conclusions

The objective of this study is to identify the best renewable energy options for development on the island of Kauai. This project surveyed the renewable resources of Kauai and found that there are several commercial renewable energy resources that could reduce or eliminate Kauai's dependence on fossil fuels for electricity production. Further, it appears that developing these indigenous resources may be possible at lower cost than the present reliance on imported fuels.

This project reviewed the prospects for twenty six renewable and advanced energy technologies. After a first phase of screening, it was found that in the near-term, biomass, municipal solid waste, hydro, wind and landfill gas were the most promising options. Each of these technologies was assessed, typical projects characterized, and their economics evaluated. The summary conclusions of these assessments are provided here, in order of the most promising resources to least.

- **Hydro** – Out of over 40 options, six promising hydro projects were identified, and all seem very economical except for, perhaps, the Upper Lihue upgrade project. The lowest cost projects are the new 4 MW Wainiha and 6.6 MW Wailua developments, at levelized costs of $58.40/MWh and $60.40/MWh (2009$), respectively. However, hydro development does have challenges on Kauai. The last new utility scale hydropower plant on Kauai, Waimea Mauka, was constructed a half century ago. The reasons for this are varied, and highlight the importance of careful project selection, a measured development strategy, and a collaborative development approach involving agricultural/industrial partners, environmental advocates, and the greater island community as a whole. The most important next steps for hydro are discussions with site owners, followed by additional site investigation and feasibility analysis.
- **Wind** – Wind resources on Kauai are good and distributed throughout the island. Theoretically, wind could meet all of Kauai's electrical energy needs if a means could be found to "firm-up" the resource with energy storage or other technologies. This study characterized seven wind sites in Kauai. The projects ranged from developments on relatively flat land with moderate wind speeds but easy site access, to exposed ridgeline developments with higher wind speeds but more difficult construction. The life-cycle economic analysis showed that these attributes roughly counteract each other. With the exception of the smaller 2 MW Kokee project, the 6.6 MW wind projects were close in levelized cost, ranging from $64/MWh to $73/MWh. No wind

site stands out as being vastly superior to others, which gives KIUC good flexibility (and negotiation position) in siting the first projects in the location deemed most suitable. Recommended next steps for wind development are preliminary siting based on discussions with land owners and detailed meteorological data collection at likely sites to establish wind speeds at turbine hub heights.

- **Municipal Solid Waste –** Municipal solid waste combustion may be a viable option for Kauai as part an integrated approach to island waste management. However, the economics of MSW strongly depend on the tipping fee received for waste disposal. This study found that at a tipping fee of $90/ton, a 7.3 MW, 300 ton per day waste to energy plant would produce power for a lower levelized cost than any of the other renewable energy options modeled: $20/MWh. However, economics are very sensitive to this tipping fee. At $56/ton (the current landfill gate fee) the levelized cost was estimated to be $108/MWh. Although this is still lower than KIUC's current avoided cost, it is not as competitive as the other renewable energy options. If KIUC is interested in exploring waste to energy further, it should discuss possible options with the County. The current landfill is running out of capacity, and new landfill capacity will need to be developed. This new landfill capacity will likely be developed at an all-in cost near the upper range of the tipping fees modeled in this study.
- **Landfill Gas** – There is currently only one viable landfill gas project on Kauai, located at the Kekaha landfill. Black & Veatch estimated that an 800 kW project using reciprocating engines could be developed after landfill closure in 2009. At $99/MWh, the levelized cost of the landfill gas project is competitive with KIUC's current avoided costs, but higher cost than several of the other project options. The project is also considered lower priority for KIUC due to the limited resource potential of LFG on the island and the relatively small project size.
- **Biomass** – Of the project options characterized in detail for this study, biomass has the most unfavorable economics. As the study progressed from the generic technology screening in Phase 1 to the detailed project characterizations in Phase 2, the estimated costs for biomass increased outside of initial expectations. The Phase 2 investigation found that the levelized cost of supplying power from a biomass fueled power station ranged from $180/MWh to $205/MWh, depending on the fuel cost. Biomass is hurt by KIUC's lack of need for baseload capacity. However, biomass, especially

derived from locally grown energy crops, does have several advantages over most other renewable energy options: (1) large amounts of baseload power could be produced from the available resource base, (2) growing and harvesting local energy crops would provide a large stimulus for Kauai's agricultural economy and help stem the loss of jobs in the sugar industry and (3) biomass crops for power may be synergistic with crops grown for ethanol fuel production. Based on these factors, it is recommended that biomass be reexamined in more detail when KIUC has greater need for capacity resources in the future.

One of the most tangible benefits of renewable energy to KIUC is lowering the exposure to rising and volatile energy prices. As a final analysis, Black & Veatch compared the levelized cost of renewable energy against KIUC's short-term avoided costs, Schedule Q. A relationship was derived showing the variation in Schedule Q rates versus cost of oil.[1] Figure 1-7 shows a comparison of the cost to generate power from each of the renewable projects analyzed in Phase 2 versus KIUC Schedule Q rates. While Schedule Q rates fluctuate with oil prices, renewable energy costs are constant. The figure shows at what oil price points renewable energy is less or more expensive than diesel engine power generation. At an oil price of about $55/bbl, landfill gas, wind, hydro, and municipal solid waste combustion are all less expensive than Schedule Q rates. However, over the range of oil prices examined for this analysis, biomass combustion is always more expensive with a lower bound of about $80/MWh. The average price for diesel oil over the past four years is approximately $45/bbl. At this price point, hydro, wind, and municipal solid waste combustion with mid to high tipping fees are less expensive than KIUC's Schedule Q rates.

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[1] Personal communication from Jeff Deren, KIUC, November 23, 2004.

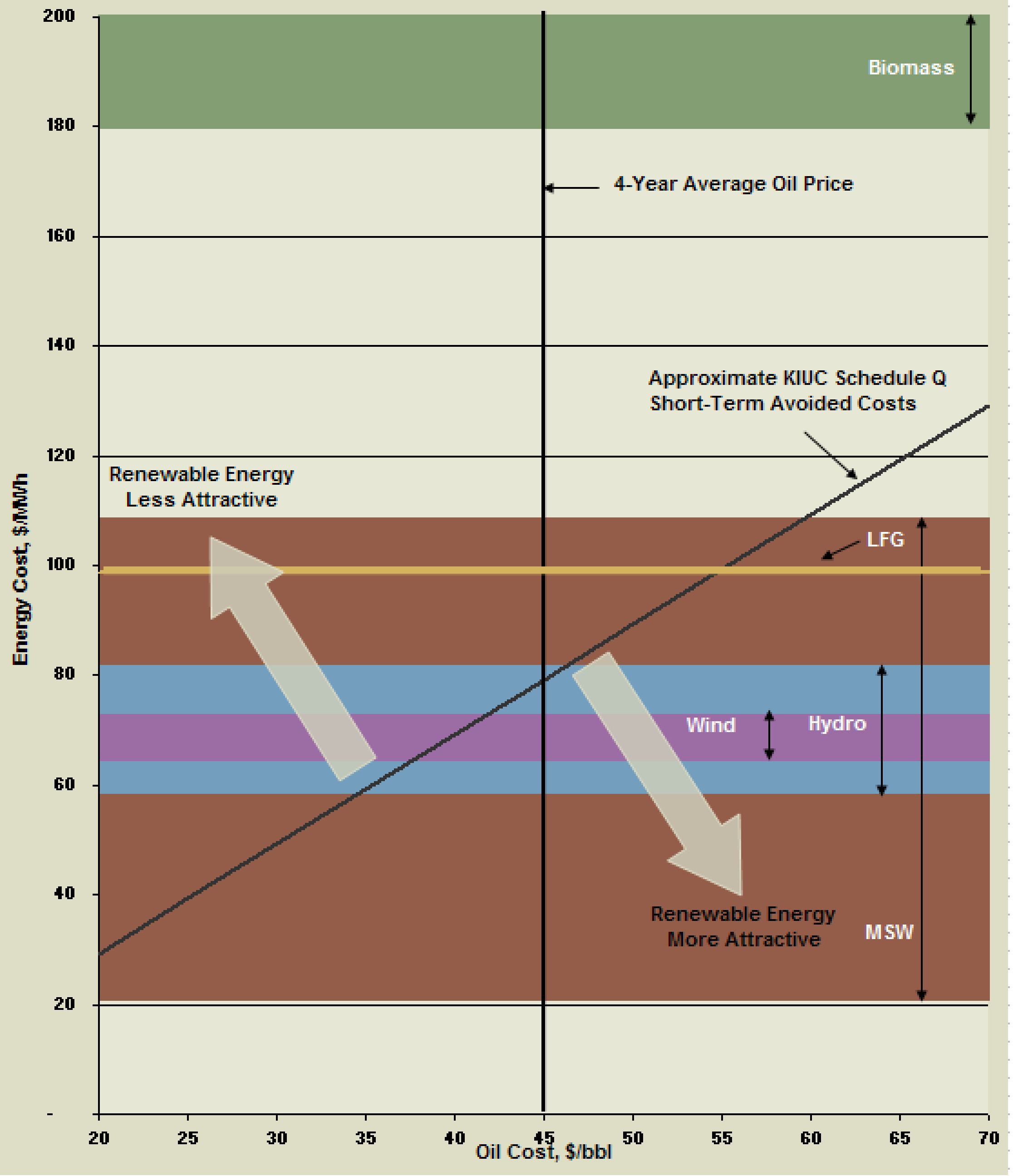

Figure 1-7. Break-Even Cost Analysis for Renewable vs. KIUC's Short Term Avoided Costs.

2.0 Introduction

The objective of this study is to identify the best renewable energy options for development on the island of Kauai. Kauai Island Utility Cooperative (KIUC) has retained Black & Veatch to undertake this assessment of renewable energy technologies and resources. This section provides an overview of the project objectives, project background, study approach, and general introduction to renewable energy including a description of Kauai's current use of renewable resources.

2.1 Background

In 2003, over 94 percent of Kauai's electricity was generated from imported fossil fuels – the highest level of fossil fuel dependence in over 25 years. Kauai's rising dependence comes during a period of record oil prices, political and military strife, and concerns about impacts on the global environment from increased consumption of fossil fuels. At the same time, Kauai is blessed with spectacular natural wonders, rich indigenous resources, and historical experience using renewable energy sources to meet a large share of its energy needs. This study examines a return to renewable energy resources as part of KIUC's integrated planning framework.

Kauai Island Utility Cooperative has been directed by the Hawaii Public Utilities Commission to update the Integrated Resource Plan (IRP) for the recently acquired Kauai Electric (KE). KE's IRP was last updated in 1997. Recognizing the important role of energy diversity, KIUC has decided to assess and address the potential role of renewable energy resources to meet the future needs of Kauai in its IRP. In addition, KIUC anticipates utilizing the results of this study to develop a strategy to meet the renewable portfolio standard (RPS) established by the Hawaiian legislature.

In June 2004, with the signing of SB2474, Hawaii's RPS goal was replaced with an enforceable standard. The standard requires that 20 percent of electricity be generated from renewable sources by 2020, with the following interim targets:

- 7 percent of net electricity sales by December 31, 2003
- 8 percent of net electricity sales by December 31, 2005
- 10 percent of net electricity sales by December 31, 2010
- 15 percent of net electricity sales by December 31, 2015
- 20 percent of net electricity sales by December 31, 2020

KIUC is currently ahead of this implementation timeline. In 2003, KIUC sourced 7.5 percent of its energy from renewable sources (including credit for solar thermal water heating).[2]

Applicable technologies for the RPS include wind, solar energy, hydropower, landfill gas, waste to energy, geothermal, ocean thermal energy conversion, wave energy, biomass (including municipal solid waste, biofuels, or fuels derived from organic sources), hydrogen fuels derived from renewable energy, or fuel cells where the fuel source is derived from renewable sources. Cofiring renewable fuels with non-renewable fuels is allowed under the RPS, but only the electricity generated from renewable fuels counts towards the RPS. This study examines all of these resources.

2.2 Objective

The objective of this project is to assess the technical, economic and market potential for reducing fossil-fueled electricity generation and peak supply on Kauai by implementing a wide range of renewable energy resource technologies. This report further aims to identify specific, promising, and actionable renewable energy projects and provide the necessary technical and economic details to support informed decision making. It is perceived that this report will form the basis of a successful and cost effective renewable energy development program over the short to mid-term.

2.3 Approach

This study is being undertaken in two phases. This Final Report is a comprehensive account of both. A previous Interim Report covered Phase 1, describing the existing use of renewable energy on the island, generation technology options, and the developable potential of the different resources. Twenty-six different technology applications are assessed in this report in the following ten categories:

1. Solid biomass
2. Biogas
3. Biofuels
4. Waste to energy
5. Hydroelectric
6. Ocean energy
7. Solar
8. Wind
9. Geothermal

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[2] Alan Oshima of Oshima Chun Fong & Chung LLP, "Kauai Island Utility Cooperative 2003 Renewable Portfolio Standards Status Report", March 30, 2004.

10. Multi-fuel generation technologies

The Interim Report concluded with the scoring of the renewable energy technology options and recommendations for further study in Phase 2 of the project. Based on the recommendations of Phase 1 and discussion with KIUC, it was determined that the following technologies would be examined in Phase 2:

- Direct fired biomass
- Municipal solid waste mass burn
- Hydroelectric
- Wind
- Landfill Gas

Phase 2 of the project characterizes the most promising options in greater detail and identifies specific project features. The findings of this project will support development of KIUC's IRP.

2.3.1 Assumptions

This report is based on hundreds of assumptions related to resource availability, costs, economic impacts and other factors. These assumptions have been developed based on Black & Veatch experience, industry inquiries, and review of literature in the field. Careful analysis of similar recent studies aided in the development of appropriate assumptions, and it is felt that the assumptions made in the report are generally conservative in nature.

Cost estimates included in this report reflect project development and installation in Hawaii. Estimates for Phase 1 of the project should be considered screening level accuracy and should not be used for definitive planning or budgeting purposes. The accuracy of the Phase 2 estimates varies by project, as more supporting details were available for some projects.

Common economic assumptions for Phase 1 were provided by KIUC and are shown in Table 2-1. Additional assumptions for Phase 2 are documented in Section 6. All costs in this document are in 2005 dollars unless otherwise noted.

Table 2-1. Economic Assumptions.

Debt Term	25
Economic Life	25
Escalation Rate	3.00%
Cost of Debt	5.00%
Cost of Equity	N/A
Debt / Equity Ratio	100 : 0
Discount Rate	5.00%
Levelized Fixed Charge Rate*	7.095%

Notes:

* Fixed charge rate is calculated by assuming 5.0 percent cost of debt with a 25 year term, 0 percent insurance, and 0 percent taxes.

2.3.2 Report Organization

This Final Report is a comprehensive documentation of all work undertaken for this project. The Final Report includes Sections 2-4 of the Interim Report (identified below), and additional sections as follows:

1. **Executive Summary** – summary of the main findings of the project.
2. **Introduction** – project background, project objective, approach, overview of renewable energy, and a review of current renewable energy use on Kauai.
3. **Renewable Technology Options** – characterization of the renewable technology options identified above including principles of operation, applications, resource characteristics, cost and performance, environmental impacts, and outlook for Kauai
4. **Renewable Energy Technology Screening –** quantitative comparison and screening of the technology options based on defined criteria (cost of electricity, resource potential, etc.). Includes summary conclusions and recommendations for Phase 2 of the project.
5. **Project Characterizations** – introduction to Phase 2, overview of approach, general assumptions for Phase 2, and economic modeling approach.
6. **Renewable Energy Financial Incentives** – overview of various tax credits, loans, grants, and other programs offering financial assistance to renewable energy projects.
7. **Biomass and Municipal Solid Waste** – Characterization of a standalone biomass plant, a standalone municipal solid waste plant, and a plant combing the two fuels.
8. **Hydro** – Identification and characterization of 6 promising hydro sites.

9. **Wind** – Identification and characterization of 7 promising wind areas.
10. **Landfill gas** – Characterization of potential landfill gas opportunity at Kekaha landfill.
11. **Final Renewable Energy Project Scoring** -- quantitative comparison and ranking of the project options based on defined criteria (cost of electricity, incentives/barriers, etc.).
12. **Conclusions** – project summary and recommendations for next steps.

2.4 Overview of Renewable Energy

Renewable energy generation technologies are based on energy sources that are practically inexhaustible in that most are solar derivatives. Such technologies are often favored by the public over conventional fossil fuel technologies because of the perception that renewable technologies are more environmentally benign. Renewable energy options include wind, solar, biomass, biogas, geothermal, hydroelectric, and ocean energy. Table 2-2 shows the power conversion technologies that have been developed to harness each of these energy sources.

Table 2-2. Renewable Energy Conversion Technologies

Renewable Resource	Energy Conversion Technology
Solar	Photovoltaic Thermal Energy Capture
Wind	Wind Turbines
Water	Hydroelectric Turbines
Ocean	Wave Energy Devices Tidal/Current Energy Turbines Thermal Energy Conversion
Geothermal	Steam Turbines Direct Use Geothermal Heat Pumps
Biomass	Combustion (direct fired, co-firing with coal) Gasification / Pyrolysis
Biogas, Biodiesel, Ethanol	Engine generators Combustion turbines Microturbines Fuel cells

Excluding hydro, renewables only supply about 2 percent of the United States' current electrical energy needs. However, the field is rapidly expanding. The following figures demonstrate the current trends for renewable energy in the United States. Perhaps more telling, more wind capacity has been installed in Europe in the last two years than any other energy generation technology. Further, worldwide wind energy additions have outpaced nuclear power additions for the past four years.

Renewable energy technologies are most competitive in niche markets (for example, off-grid electrification) or when public sentiment will support government subsidies or special pricing mechanisms such as "green" pricing.

It should be noted that almost all renewable energy technologies have high initial capital costs and low operating costs. This fact makes financing terms for renewable energy projects very important. Access to low cost capital can have a significant impact on life-cycle costs and improve the economics of these projects substantially.

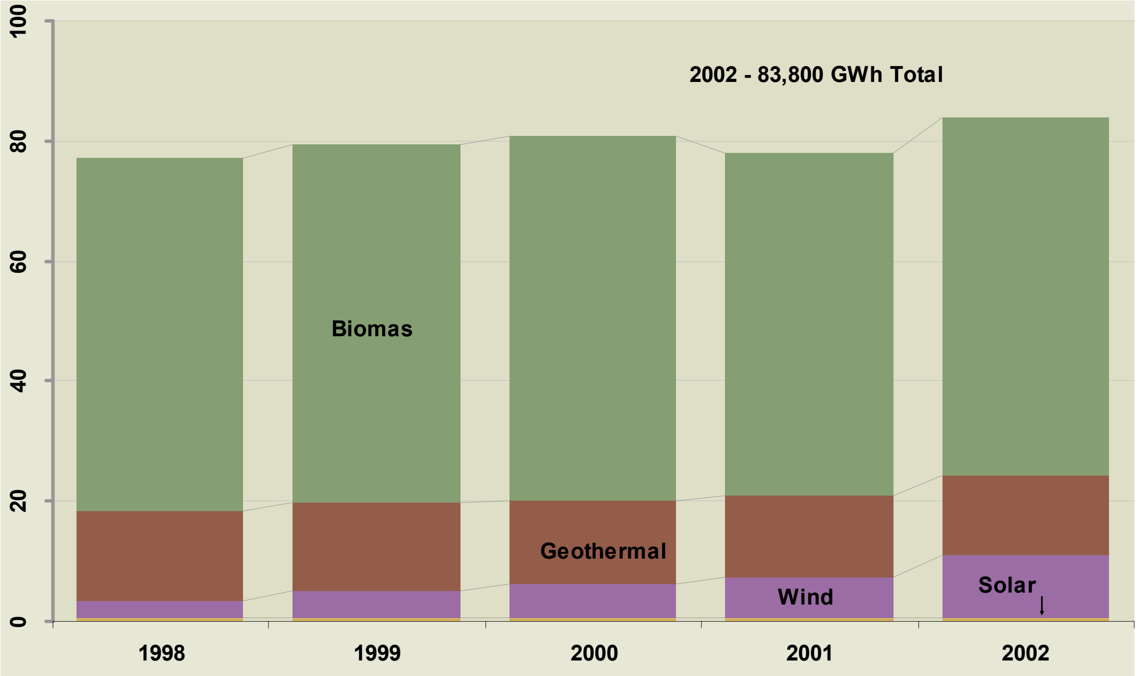

Figure 2-1. US Net Renewable Electricity Generation, GWh (1000's). (EIA 2002)

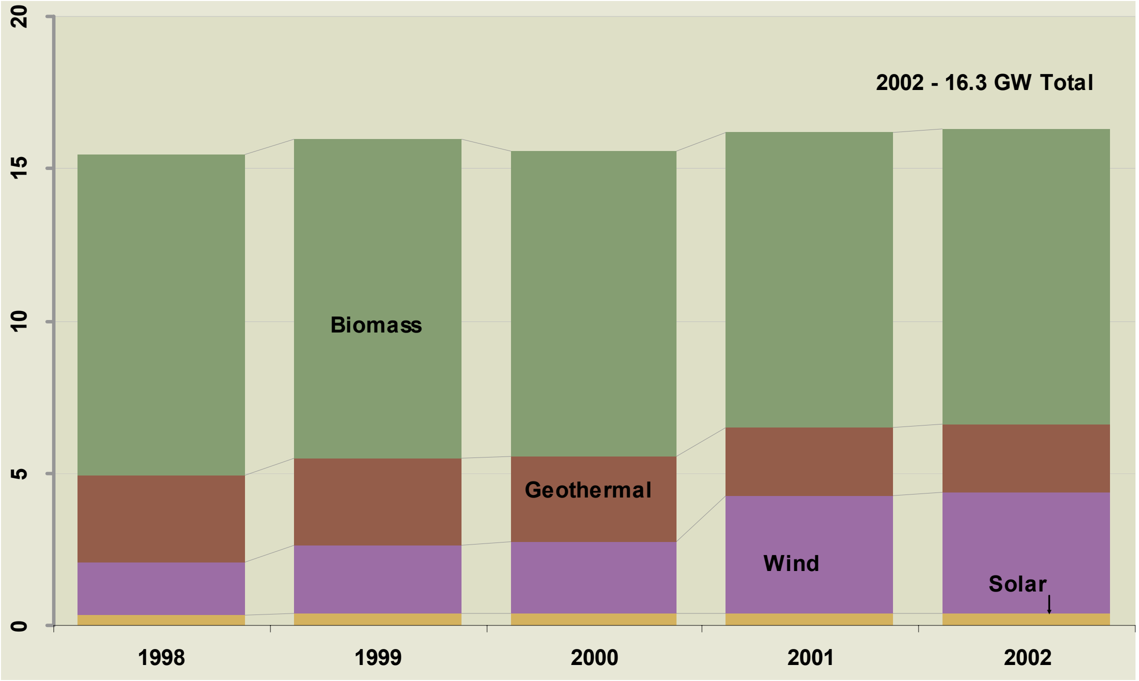

Figure 2-2. US Net Renewable Electrical Capacity, GW. (EIA 2002)

2.5 Review of Current Renewable Energy Use on Kauai

Kauai has historically relied upon a mix of renewable and conventional energy sources for power generation. There are no fossil fuel resources on the island; consequently all fuel is imported. The lack of fossil fuel resources initially spurred development of biomass and hydroelectric projects to power the island's sugar industry, the first major electric consumer on the island. In fact, Kauai's original electric company started as a subsidiary of McBryde Sugar Co. Several hydroelectric and biomass fueled power plants were developed to provide electricity for irrigation, milling and production operations. In the past, electricity from these sources has been a substantial source of energy for the island. In the early 1980s, hydro and biomass accounted for upwards of 40 to 50 percent of electricity generated on the island. However, in 2003, KIUC only sourced 7.5 percent of its energy from renewable sources.[3] The amount of renewable energy generation has been in a state of decline since the early 1980s, see Figure 2-3.

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[3] Alan Oshima of Oshima Chun Fong & Chung LLP, "Kauai Island Utility Cooperative 2003 Renewable Portfolio Standards Status Report", March 30, 2004. Includes credit for solar water heating, which displaces electricity production.

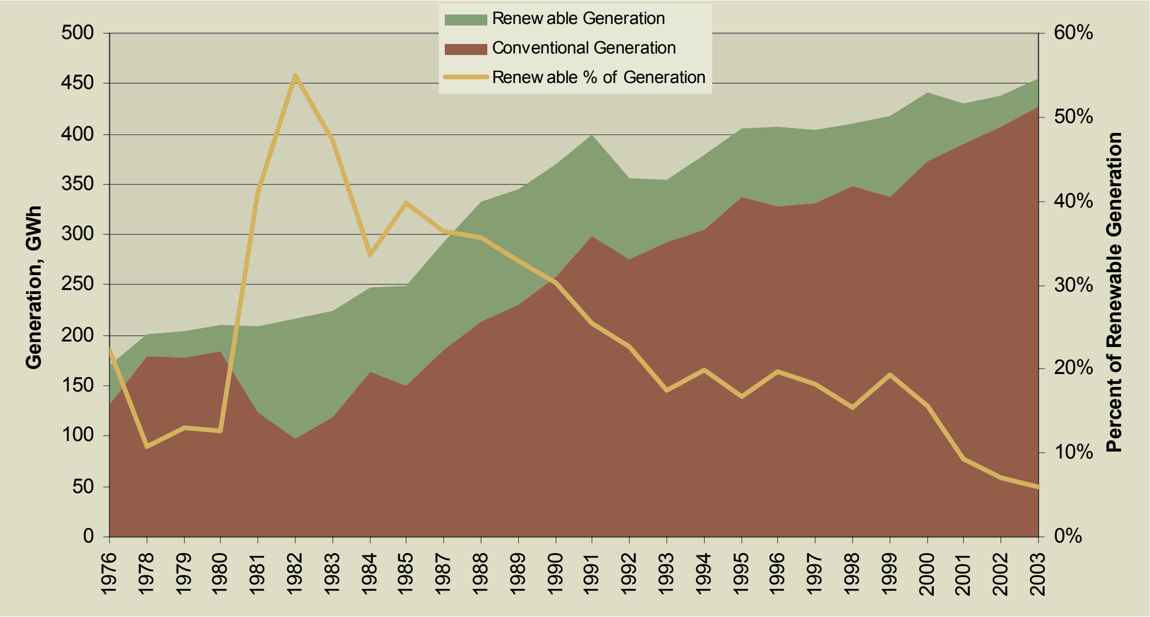

Figure 2-3. Historic Electricity Generation in Kauai (Data: KIUC).

The amount of renewable energy supplied by industrial producers has declined as sugar production has declined on the island. In 2002, the Lihue Plantation's bagasse power plant was shut down, which removed 14 MW of firm renewable energy from KIUC's portfolio. This power purchase agreement had supplied an average of 44,000 MWh per year and had accounted for 9 to 12 percent of annual energy sales.

In addition to the declining output from renewable facilities, the need for electricity on the island has steadily grown. As fossil fuel prices were relatively low during the 1990s, there was little economic impetus to examine renewable alternatives for new generation. Today's higher fossil fuel prices coupled with the new state RPS has recast the decision making environment.

Table 2-3 shows the installed capacity of renewable energy generation on the island of Kauai. Table 2-4 shows that the majority of electricity is currently produced by fossil fuel sources on Kauai.

Table 2-3. Installed Kauai Renewable Energy Generating Capacity.

Plant	Owner	Technology	Capacity, kW
Waimea Mauka Hydro	State ADC[a]	Hydro	1,000
Waiawa Hydro	State ADC[a]	Hydro	500
Lihue Lower	KIUC	Hydro	600
Lihue Upper	KIUC	Hydro	800
Wainiha Hydro	Kauai Coffee	Hydro	3,700
Kalahea Hydro	Kauai Coffee	Hydro	1,000
Waiahi Hydro	Gay & Robinson	Hydro	1,300
Lihue Plantation[b]	Lihue Plantation	Biomass Comb.	21,800
Gay & Robinson	Gay & Robinson	Biomass Comb.	4,000
Solar PV Systems	Various	Solar PV	42
Total			38,742

Source: KIUC, DBEDT.

Notes:

[a] State Agribusiness Development Corporation

[b] Currently not operating.

Table 2-4. 2003 Kauai Electricity Generation.

Generation Source	Generation, MWh	Percent
Fossil Fuels		
Steam Plant	9,324	2.1
Diesel 1-5	158,100	34.8
Diesel 6-9	1,304	0.3
Gas T1 Hitachi	16,829	3.7
Gas T2 JBE	28,316	6.2
KPP Diesel	14,236	3.1
KPP Naphtha	199,495	43.9
Fossil Fuels Subtotal	427,604	94.1
Renewable		
Waiahi	588	0.1
Kekaha Sugar / ADC	2,192	0.5
McBryde / Kauai Coffee	21,422	4.7
Olokele / Gay & Robinson	2,656	0.6
Renewable Subtotal	26,858	5.9
Total	**454,462**	**100**

Source: KIUC

3.0 Renewable Energy Technology Options

The first step in the development of generation alternatives involves the identification of generic generation technologies whose technical and cost characteristics cause them to be worthwhile candidates for inclusion in full-fledged alternative plans. The objective of this section is to characterize the various renewable energy technologies suitable for application in Kauai. The information contained in this section will be used to screen technologies for further investigation later in the project.

Renewable energy sources are practically inexhaustible in that most derive their energy from the sun. Technologies to harness renewable energy are diverse and include wind, solar, biomass, biogas, geothermal, hydroelectric, and ocean energy. Steady advances in equipment and operating experience spurred by government incentives have lead to many mature renewable technologies. The technical feasibility and cost of energy from nearly every form of renewable energy have improved since the early 1980s. However, most renewable energy technologies struggle to compete economically with conventional fossil fuel technologies, and in most countries the renewable fraction of total electricity generation remains small. This is true despite a huge resource base that has potential to provide many multiples of current electricity demand. Nevertheless, the field is rapidly expanding from niche markets to making meaningful contributions to the world's electricity supply.

This section provides an overview of the following renewable energy options:

1. Solid biomass
    1.1 Direct fired
    1.2 Cofiring
2. Biogas
    2.1 Anaerobic digestion
    2.2 Landfill gas
3. Biofuels
    3.1 Ethanol
    3.2 Biodiesel
4. Waste to energy
    4.1 Mass burn
    4.2 Refuse derived fuel
    4.3 Plasma arc
5. Hydroelectric
6. Ocean energy
    6.1 Ocean thermal energy conversion

  - 6.2 Wave
  - 6.3 Tidal
- 7. Solar
  - 7.1 Solar photovoltaic
    - 7.1.1 Residential
    - 7.1.2 Commercial
  - 7.2 Solar thermal
    - 7.2.1 Parabolic Trough
    - 7.2.2 Parabolic Dish Stirling
    - 7.2.3 Central Receiver
    - 7.2.4 Solar Chimney
- 8. Wind
  - 8.1 Wind Farm
  - 8.2 Distributed Wind
- 9. Geothermal
- 10. Multi-fuel generation technologies
  - 10.1 Reciprocating engines
    - 10.1.1 Spark Ignition
    - 10.1.2 Compression Ignition
  - 10.2 Small combustion turbines
  - 10.3 Microturbines
  - 10.4 Fuel cells

Generally, each technology is described with respect to its principles of operation, applications, resource characteristics, cost and performance, environmental impacts, and outlook for Kauai. The alternatives have been presented with a typical range for performance and cost, and the generic data provided should not be considered definitive estimates. The performance and costs are based on a representative size and installation in Hawaii. Estimates are based on Black & Veatch project experience, vendor inquiries, and a literature review. In addition, an overall levelized cost range for the general technology type is provided. This levelized cost of energy accounts for capital cost (including direct and indirect costs), fuel, operations, maintenance, and other costs over the typical life expectancy of the unit. At this point in the analysis, no financial incentives have been included in the levelized cost calculation.

Although a few of the technologies are not commercially viable at this time, cost and performance data were assembled as available to provide a complete screening-level resource planning evaluation.

3.1 Solid Biomass

Biomass is any material of recent biological origin. There is a huge variety of biomass resources, conversion technologies, and end products, as shown in the figure below. This report focuses on electricity generation technologies. Electricity generation from biomass is the second most prolific source of renewable electricity generation after hydro.

Biomass Sources

- § Forests
  - - Natural regrowth
  - - Energy forests
  - - Forest residues
  - - Processing residues
- § Agriculture
  - - Crop residues
  - - Processing residues
  - - Energy crops
- § Wastes
  - - Municipal
  - - Industrial

Processing

- § Drying
- § Extrusion
- § Compression
- § Chipping
- § Carbonization
- § Anaerobic digestion
- § Fermentation
- § Gasification
- § Pyrolysis
- § Fischer tropsch etc.processors

Fuel Products

- § Solid Fuels
  - - Charcoal
  - - Wood chips
  - - Pellets/ briquettes
- § Gaseous fuels
  - - Methane
  - - Pyrolysis gas
  - - Producer gas
- § Liquid fuels
  - - Plant esters/oils
  - - Ethanol
  - - Methanol/alcohols
  - - Pyrolysis liquids
  - - Other liquids

Markets

- § Electricity
- § Heat
- § Solid fuels e.g.(domestic)
- § Transport

Source: Renewable Energy World, March-April 2003.

Figure 3-1. Biomass Sources, Processes, Products, and Markets.

This section of the report describes solid biomass power options: direct fired biomass and cofired biomass. Other sections describe biogas, biofuel (e.g., ethanol), and waste to energy technologies.

3.1.1 Direct Fired Biomass

According to the US Department of Energy, there is over 40,000 MW of installed biomass combustion capacity worldwide. The majority of this capacity is in combined heat and power applications in the pulp and paper industry.

Direct biomass combustion power plants in operation today essentially use the same steam Rankine cycle introduced into commercial use 100 years ago. By burning biomass, pressurized steam is produced in a boiler and then expanded through a turbine to produce electricity. Prior to combustion in the boiler, the biomass fuel may require some processing to improve the physical and chemical properties of the feedstock. Furnaces used in the combustion of biomass include spreader stoker-fired, suspension-fired, fluidized bed, cyclone and pile burners. Advanced technologies, such as integrated biomass gasification combined cycle and biomass pyrolysis, are currently under development and are not considered for commercial applications in this study.

Applications

Wood is the most common biomass fuel. Other biomass fuels include agricultural residues such as bagasse, dried manure and sewage sludge, black liquor, and dedicated fuel crops such as fast growing grasses and eucalyptus. There are also many municipal waste burners installed throughout the world employing similar conversion technology. However, the construction of new municipal waste combustion plants has become difficult in the United States due to environmental concerns regarding toxic air emissions. (See the waste to energy section for further discussion).

Figure 3-2. 35 MW Biomass Combustion Plant.

The capacity of biomass plants is usually less than 50 MW because of the dispersed nature of the feedstock and the large quantities of fuel required. Furthermore, biomass plants will commonly have lower efficiencies than modern coal plants. The efficiency is lower because of the smaller scale of the plants and the lower heating value and higher moisture content of the biomass fuel compared to coal. Additionally, biomass is typically more expensive and lower in density than coal. These factors usually limit use of direct fired biomass technology to inexpensive or waste biomass sources.

In addition to electrical generation, there are many industrial plants that burn their own biomass waste to produce thermal energy for heating and process applications. The small scale production of combined heat and power is seen as one of the more promising biomass applications.

Resource Availability

Wood and wood waste are the primary biomass resources and are typically concentrated in areas of high forest products industry activity. In rural areas the agricultural economy can produce significant fuel resources that may be collected and burned in biomass plants. These resources include bagasse, corn stover, rice hulls, wheat straw, and other agricultural residues. Energy crops, such as switchgrass and short rotation woody crops, have also been identified as potential biomass sources. In urban areas, a biomass project might burn wood wastes such as construction debris, pallets, yard and tree trimmings, and railroad ties. Locally grown and collected biomass fuels are relatively labor intensive and can provide substantial employment benefits to rural economies. Generally, availability of sufficient quantities of biomass is not as large of a concern as delivering the biomass to the power plant at a reasonable price.

Cost and Performance Characteristics

Table 3-1 provides typical characteristics of a 30 MW biomass plant using a traditional stoker boiler and Rankine steam cycle. Three different fuel prices are included for comparison: $0/MBtu, $3/MBtu and $6/MBtu. The zero cost fuel is indicative of a plant using a biomass fuel that the supplier would otherwise need to dispose of. The highest price, $6/MBtu, is equivalent to a price of about $100 per dry ton, which is at the very upper range of estimates for energy crops. The final price, $3/MBtu is probably a reasonable estimate for the average price of delivered biomass on the island. Further investigation would be required to better define the expected price.

Table 3-1. Direct Biomass Combustion Technology Characteristics.

Performance	
Typical Duty Cycle	Baseload
Net Plant Capacity, MW	30
Net Plant Heat Rate (HHV), Btu/kWh	14,500
Capacity Factor, percent	70-90
Economics	
Capital Cost, $/kW	2,600 – 3,900
Fixed O&M, $/kW-yr	78
Variable O&M, $/MWh	10
Levelized Cost, $6/MBtu Fuel, $/MWh	173-186
Levelized Cost, $3/MBtu Fuel, $/MWh	114 -127
Levelized Cost, $0/MBtu Fuel, $/MWh	55-68
Technology Status	
Commercial Status	Commercial
Installed US Capacity, MW	4,425*
Kauai Potential	Very Good

Notes:
* Black & Veatch estimate for direct-fired plants only. Numerous plants also cofire biomass fuels, and these are not included in this estimate. See also Table 3-4.

Environmental Impacts

Biomass power projects must maintain a delicate balance to ensure long term sustainability with minimal environmental impact. Several states impose specific criteria on biomass power projects for them to be classified as "renewable". A key concern is sustainability of the feedstock. Most biomass projects target utilization of biomass waste material for energy production, saving valuable landfill space. Targeting certain wastes for power production (such as animal manure) can also address other emerging environmental problems. Projects relying on forestry or agricultural products must be careful to ensure that fuel harvesting and collection practices are sustainable and provide a net benefit to the environment.

Biomass utilization has several positive impacts. Unlike fossil fuels, biomass is viewed as a carbon-neutral power generation fuel. While carbon dioxide is emitted during biomass combustion, a nearly equal amount of carbon dioxide is absorbed from the atmosphere during the biomass growth phase. Further, biomass fuels contain little sulfur compared to coal, and so produce less sulfur dioxide. Finally, unlike coal, biomass fuels typically contain only trace amounts of toxic metals, such as mercury, cadmium, and lead.

On the other hand, biomass combustion still must cope with some of the same emissions issues as larger coal plants. Primary pollutants are nitrogen oxides, particulate matter, and carbon monoxide. Standard air quality control technologies are used to manage these pollutants.

Kauai Outlook

There is very good potential for power production from biomass combustion in Kauai. Until recently, the island has generated a significant portion of its power from bagasse, the fibrous residue from sugarcane. Gay & Robinson, the only remaining sugar plantation, supplies a small amount of power to KIUC. Unlike most other renewable energy options, the past experience with bagasse indicates that the island has not only the potential biomass, but also the human resources and technical know-how to staff and successfully operate a biomass plant. Further, the recent closure of the Lihue bagasse fired power plant may represent a unique opportunity to salvage equipment for reuse in a new or refurbished biomass plant.

Kauai's biomass resources are diverse. A survey of existing biomass resources was recently competed for the DBEDT.[4] The survey results for Kauai are summarized in Table 3-2.

As shown in the table, residues from sugar production (bagasse and cane trash) currently comprise the largest biomass resource on the island. However, Gay & Robinson is exploring alternative uses for their bagasse, including ethanol production. In addition, the future of sugar production on the island is quite uncertain, making exclusive reliance on sugar residues unwise. The other major existing resource identified in the study is municipal solid waste, which is discussed more thoroughly in Section 3.4. The existing biomass and waste resources identified in the study represent a moderate potential source of energy. If used in a single baseload plant of about 17 MW, they could generate about 200 GWh/yr of energy. Black & Veatch also surveyed the island for other sources of biomass waste not identified in the study. These include residues from corn, coffee, and guava production. Available quantities appear somewhat limited, but further investigation is warranted if biomass passes the screening phases.

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[4] University of Hawaii, Hawaii Natural Energy Institute, "Biomass and Bioenergy Resource Assessment State of Hawaii", available at: http://www.hawaii.gov/dbedt/ert/biomass-assessment.pdf, December 2002.

Table 3-2. Kauai Biomass Resource Estimates.

Resource	Basis[a]	Quantity, tons/yr	Combustion Fuel?[b]	Est. Heat Content, MBtu/ton	Potential Heat, MBtu/yr	Potential Energy, GWh/yr[c]	Potential Capacity, MW[d]
Swine Manure	dry	180	No				
Poultry Litter	dry	1,520[e]	No				
Bagasse Fiber	dry	18,000[f]	Yes	16	288,000	19.9	2.8
Molasses	AR	15,000	No				
Cane Trash	dry	37,000	Yes	16	592,000	40.8	5.8
Municipal Waste	AR	80,000[g]	Yes	10	800,000	55.2	7.9
Sewage Sludge	dry	246	Yes	14	[h]	[h]	[h]
Fats/Oil/Grease	dry	800	Yes	34	27,200	1.9	0.3
Total					1,707,200	118	16.8

Source: Except as noted, tonnage estimates adapted from University of Hawaii, Hawaii Natural Energy Institute. Energy related estimates by Black & Veatch.

Notes:

[a] Basis for tonnage estimate. Dry or as-received (AR).

[b] Indicates if the fuel is suitable for combustion in its raw form.

[c] Potential annual electricity generation by burning the fuel in a multi-fuel power plant assuming a net plant heat rate of 14,500 Btu/kWh.

[d] Potential power capacity assuming an annual capacity factor of 80 percent.

[e] Includes poultry litter from Hawaii and Maui counties.

[f] Excess bagasse not currently used. Gay and Robinson processed a total of 74,000 dry tons of bagasse in 2002 and used 56,000 dry tons to meet internal steam and power needs.

[g] Estimate from landfill gas study, based on more recent data. Source: SCS Engineers for US EPA, "Landfill Gas Utilization Feasibility Study Kekaha Landfill", April 2004.

[h] Included with municipal solid waste.

In addition to the existing resources identified, there is very good potential for development of new biomass resources on Kauai. For example, Bill Cowern of Kauai Mahogany has started a plantation of mahogany and eucalyptus and will soon begin harvesting material. As of mid-2004, 1,100 acres had been planted, with a total of 3,000 acres planned. The annual maintenance of growing stock and harvesting processes will generate significant amounts of residue, up to 35,000 air-dried tons per year when fully operational. Mr. Cowern has indicated that he believes he will have enough residue to generate 3 MW of power for his own use in a small power plant.[5] If used in a larger, more efficient utility scale power plant, this same quantity of residue might be enough for 5 MW of capacity producing 35 GWh/yr of energy annually. As with bagasse, this resource is dependent on the viability of the underlying business.

If waste agricultural resources are not present or do not develop in sufficient quantities to support a biomass plant, dedicated energy crops could be grown on the

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[5] Bill Cowern (Kauai Mahogany), personal communication, June 15, 2004.

island, albeit at higher cost. The decline of the sugar industry in Hawaii represents a good opportunity to develop new energy crop farms. Although some former sugar land has been put to new uses (such as coffee and cattle), these generally use only a small portion of the land formerly in sugar production. As stated in a recent report, "Large quantities of productive and well-developed agricultural lands presently exist in Hawaii in 'ready to plant' condition."[6]

Energy crop options for Kauai generally consist of woody crops and grasses. Research trials have identified banagrass as one of the more promising energy crop options. Banagrass is a fast-growing variety of elephantgrass with yields projected to range from 18 to 22 dry tons per acre, per year. Banagrass could be grown on land currently zoned for agriculture and possibly also conservation land. Total land zoned agricultural in Kauai is about 140,000 acres, although only a fraction of this is currently farmed.[7] Banagrass has a heat content of approximately 16 MBtu/dry ton. Theoretically, if all 140,000 acres were used to grow banagrass yielding 20 dry tons per acre per year, approximately 2.8 million dry tons of banagrass could be harvested per year. This would be enough to generate over 3,000 GWh/yr from a plant capacity of 440 MW. If only 20 percent of this land was available to grow banagrass (an amount equal to 28,000 acres, less than the amount of land used for sugarcane in the mid-1990s) this would be enough to generate over 600 GWh/yr from a plant capacity of about 90 MW. Banagrass alone could supply all the electricity needs of Kauai, while substantially reinvigorating the island's agricultural industry.

There is good potential from a variety of biomass sources on the island. It is possible to design a biomass facility to accept a diverse fuel mix, possibly even including imported coal. Given the uncertainty about future availability of biomass on the island, such an approach is advisable. The developable potential for biomass is summarized in the following table.

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[6] Charles Kinoshita and Jiachun Zhou, "Siting Evaluation for Biomass-Ethanol Production in Hawaii", available at: http://www.hawaii.gov/dbedt/ert/bioethanol/ch10.html, 1999.

[7] Kinoshita and Zhou.

Table 3-3. Developable Potential from Direct Fired Biomass.

Year	Energy, GWh	Capacity, MW	Notes
3	97.4	13.9	Constrained to near term available fuels (tree farm trimmings and resources in Table 3-2, except MSW). Project would need to be repowering of Lihue power station to be available in 3 years.
5	714	102	Includes near-term fuels and energy crops on 20 percent of agricultural lands, excludes MSW
10	714	102	
20	714	102	

3.1.2 Biomass Cofiring

An economical way to burn biomass is to cofire it with coal in existing plants. Cofired projects are usually implemented by retrofitting a biomass fuel feed system to an existing coal plant, although greenfield facilities can also be readily designed to accept a variety of fuels.

A major challenge to biomass power is that the dispersed nature of the feedstock and high transportation costs generally preclude plants larger than 50 MW. By comparison, coal power plants rely on the same basic power conversion technology but have much higher unit capacities, exceeding 1,000 MW. Due to their scale, modern coal plants are able to obtain higher efficiency at lower cost. Through cofiring, biomass can take advantage of this high efficiency at a more competitive cost than a stand-alone direct fired biomass plant.

Applications

There are several methods of biomass cofiring that could be employed for a project. The most appropriate system is a function of the biomass fuel properties and the coal boiler technology.

Provided they were initially designed with some fuel flexibility, stoker and fluidized bed boilers generally require minimal modifications to accept biomass. Simply mixing the fuel into the coal pile may be sufficient.

Cyclone boilers and pulverized coal (PC) boilers (the most common in the utility industry) require smaller fuel size than stokers and fluidized beds and may necessitate additional processing of the biomass prior to combustion. There are two basic approaches to cofiring in this case. The first is to blend the fuels and feed them together to the coal processing equipment (crushers, pulverizers, etc.). In a cyclone boiler, generally up to 10 percent of the coal heat input could be replaced with biomass using this method. The smaller fuel particle size of a PC plant limits the fuel replacement to perhaps 3 percent. Higher cofiring percentages (around 10 percent) in a PC unit can be accomplished by developing a separate biomass processing system at somewhat higher cost.

Even at these limited cofiring rates, plant owners have raised numerous concerns about negative impacts of cofiring on plant operations. These include:

- Negative impact on plant capacity
- Negative impact on boiler performance
- Ash contamination impacting ability to sell coal ash
- Increased operation and maintenance costs
- Limited potential to replace coal (generally accepted to be 10 percent on an energy basis)
- Minimal nitrogen oxide reduction potential
- Boiler fouling/slagging due to high alkali in biomass ash
- Negative impacts on selective catalytic reduction air pollution control equipment (catalyst poisoning)

These concerns have been a major obstacle to more widespread biomass cofiring adoption. Most of these concerns can be addressed by using an external biomass gasifier to convert the energy of the solid biomass into a low energy gas ("syngas") to be fired in the boiler. Using gasification technology, it is expected that 25 percent or more of the coal heat input could be displaced without significant operational problems. Additionally, the syngas can be used as a reburn fuel to significantly reduce NO_x emissions. The gasification system has a higher cost than the other cofiring approaches, but still a fraction of the cost of a new direct-fired plant.

Coal and biomass cofiring may also be considered for new power plants. Designing the plant from the outset to accept a diverse fuel mix would allow the specifications for the boiler to incorporate the biomass fuel into the design, ensuring high efficiency with low operational and maintenance impacts. Fluidized bed technology is often the preferred boiler technology as it has inherent fuel flexibility. There are many fluidized bed units around the world that burn a wide variety of fuels, including biomass. An example is the 240 MW CFB owned by Alholmens Kraft Oy in Finland which burns a mix of wood, peat and lignite. This unit was supplied by Kvaerner Pulping and was commissioned in 2001. The plant is shown in Figure 3-3.

Figure 3-3. Alholmens Kraft Multi-Fuel CFB (Source: Kvaerner).

Resource Availability

For viability, the coal plant should be within 100 miles of a suitable biomass resource. In the United States, which has the largest installed biomass power capacity in the world, biomass power plants provide 6,200 MW of power to the national power grid. Of the total electricity produced in 2001, coal accounted for 1.9 trillion kWh, or 51 percent. Conversion of as little as five per cent of this generation to biomass cofiring would nearly quadruple electricity production from biomass.

Cost and Performance Characteristics

Table 3-4 provides typical characteristics for a cofired plant using biomass as fuel. Three different fuel prices are included for comparison: $0/MBtu, $3/MBtu and $6/MBtu. The zero cost fuel is indicative of a plant using a biomass fuel that the supplier would otherwise need to dispose of. The highest price, $6/MBtu, is equivalent to a price of about $100 per dry ton, which is at the very upper range of estimates for energy crops. The final price, $3/MBtu is probably a reasonable estimate for the average price of delivered biomass on the island. If biomass fuel is available at a lower cost than the plant's coal supply, biomass cofiring could actually result in cost savings at the plant and a "negative cost" renewable energy resource. Further investigation would be required to better define the expected price. The low end of the capital cost range corresponds to a direct fuel mixing system, while the upper end reflects a biomass gasification system.

Table 3-4. Cofired Biomass Technology Characteristics.

Performance	
Typical Duty Cycle	Typically baseload, depends on host
Net Plant Capacity, MW	1-50 (typically 1-25 percent of host)
Net Plant Heat Rate, Btu/kWh	9,000-12,000 (same as host)
Capacity Factor, percent	50-90 (same as host)
Economics	
Incremental Capital Cost, $/kW	100-800
Incremental Fixed O&M, $/kW-yr	7-26
Levelized Cost, $6/MBtu Fuel, $/MWh	76-113
Levelized Cost, $3/MBtu Fuel, $/MWh	39-64
Levelized Cost, $0/MBtu Fuel, $/MWh	2.7-15
Technology Status	
Commercial Status	Commercial
Installed US Capacity, MW	2,100*
Kauai Potential	Poor without host coal plant, otherwise very good

Notes:
* Black & Veatch estimate for the biomass portion of plants that cofire coal and biomass. Actual capacity is unknown as the degree of cofiring varies substantially.

Environmental Impacts

As with direct fired biomass plants, the biomass fuel supply must be collected in a sustainable manner. Assuming this is the case, cofiring biomass in a coal plant generally has overall positive environmental effects. The clean biomass fuel typically reduces emissions of sulfur, carbon dioxide, nitrogen oxides and heavy metals, such as mercury. Further, compared to other renewable resources, biomass cofiring directly offsets fossil fuel use.

Critics are opposed to cofiring biomass with coal because they feel it is a form of "green washing" dirty coal plants. They believe that biomass could be used to justify extended lives for coal plants. For these reasons, they argue that the cofired biomass should not be counted as renewable.

Kauai Outlook

As discussed in the previous section, there are a large variety of potential biomass fuels on the island that could be used to supplement coal. However, the outlook for cofiring biomass with coal clearly depends on the development of a new coal-fired power plant on the island. Without coal or any near term plans for coal, cofiring is not a viable option. The last Kauai Electric Integrated Resource Plan (1997) identified a potential 24 MW coal capacity addition in 2014. Biomass could be a meaningful and cost effective contributor to the fuel mix for this plant. It is likely that up to 25 percent of the heat input could be feasibly (technically and economically) provided by biomass. This would generate about 40 GWh/yr assuming an 80 percent capacity factor. Considering this addition, the developable potential for biomass cofiring is summarized in the following table.

Table 3-5. Developable Potential from Biomass Cofiring.

Year	Energy, GWh	Capacity, MW	Notes
3	0	0	Potential is not limited by resource, but coal capacity. Last IRP called for 24 MW of coal capacity in 2014.
5	0	0	
10	42	6	Assumes cofiring biomass at 25 percent of 24 MW coal plant at 80 percent capacity factor.
20	84	12	Assumes another 24 MW unit is added, with similar cofiring.

3.2 Biogas

The biogas technology characterization generally pertains to the products of anaerobic digestion of manure and gas produced from landfills. The following sections detail the formation of these fuels and how each can be used to produce useful energy.

3.2.1 Anaerobic Digestion

Anaerobic digestion is the naturally occurring process that occurs when bacteria decompose organic materials in the absence of oxygen. The byproduct gas has 50 to 80 percent methane content. The most common applications of anaerobic digestion use industrial wastewater, animal manure, or human sewage. According to the European Network of Energy Agencies' ATLAS Project, the world wide deployment of anaerobic digestion in 1995 was approximately 6,300 MW_{th} for agricultural and municipal wastes.

This is estimated to increase to 20,130 MW_{th} in 2010 with the majority of that growth being in municipal wastewater digestion.

Applications

Anaerobic digestion is commonly used in municipal wastewater treatment as a first stage treatment process for sewage sludge. Digesters are designed to convert the organic material or sewage sludge into safe and stable biosolids and methane gas. The use of anaerobic digestion technologies in wastewater treatment applications is increasing because it results in a smaller quantity of biosolids residue compared to aerobic technologies. Power production is typically a secondary consideration in digestion projects. Increasingly stringent agricultural manure and sewage sludge management regulations are the primary drivers.

In agricultural applications, anaerobic digesters can be installed anywhere there is a clean, continuous source of manure. It is highly desirable that the animal manure be concentrated, which is common at dairy and hog farms. (Poultry litter is dryer and more suitable for direct combustion.) Dairy farms use different types of digesters depending upon the type of manure handling system in place at the farm and the land area available for the digester. A 600 to 700 head dairy farm generally produces sufficient manure to generate about 85 kW. Hog farms typically use simple lagoon digesters because of the wetter manure and generate approximately 50 kW for every 500 swine.

Figure 3-4. 500 m^3 Digester Treating Manure from a 10,000 Pig Farm in China.[8]

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[8] Image source: Perdue University, http://pasture.ecn.purdue.edu/~jiqin/PhotoDigester/PhotosDigesters.html.

In addition to wastewater and agricultural residues, Los Angeles Department of Water has announced a new agreement to purchase power from a 40 MW anaerobic digestion facility that will process 3,000 tons per day of municipal green waste (such as landscape trimmings and food waste) to produce biogas for power production. The facility is scheduled to be on-line by 2009. This facility would be the largest of its kind in the world. There are various other high-solids digestions systems installed world wide. These are primarily in Europe and Japan and use municipal solid waste and green waste as feedstocks.

Biogas produced by anaerobic digestion can be used for power generation, direct heat applications, and/or absorption chilling. Reciprocating engines are by far the most common power conversion device, although trials with microturbines and fuel cells are underway. (For further discussion of conversion technology options see Section 3.10.) Agricultural digesters frequently satisfy the power demands for the farm on which they are installed, but do not provide significant exports to the grid. Municipal sewage sludge digesters generally produce enough gas to satisfy about half the wastewater treatment plant electrical load. Power production is typically a secondary consideration in digestion projects. Increasingly stringent agricultural manure and sewage sludge management regulations are the primary drivers.

Resource Availability

For on-farm manure digestion, the resource is readily accessible and only minor modifications are required to existing manure management techniques. In some cases, economies of scale may be realized by transporting manure from multiple farms to a central digestion facility. For central plant digestion of manure from many farms, the availability of a large number of livestock operations within a close proximity is necessary to provide a sufficient flow of manure to the facility. However, the larger size of regional facilities does not necessarily guarantee better economics because of high manure transportation costs. For anaerobic digestion of municipal sewage wastes the resource is readily available at the wastewater treatment plant.

Cost and Performance Characteristics

Table 3-6 provides typical characteristics of farm-scale dairy manure anaerobic digestion systems utilizing reciprocating engine technology.

Table 3-6. Anaerobic Digestion Technology Characteristics.

Performance	
Typical Duty Cycle	Baseload
Net Plant Capacity, MW	0.085
Capacity Factor, percent	70-90
Economics	
Capital Cost, $/kW	3,000-4,900
Variable O&M, $/MWh	20
Levelized Cost, $/MWh*	57-77
Technology Status	
Commercial Status	Commercial
Installed Worldwide Capacity, MW_{th}	6,300
Kauai Potential	Poor

* Fuel cost of $0/MBtu assumed.

Environmental Impacts

Anaerobic digesters have multiple positive environmental impacts. First, they provide a dependable waste stabilization process that significantly reduces pathogens in the waste stream. Second, they eliminate odor problems. Third, they reduce methane emissions relative to atmospheric decomposition of manure. These emissions are a significant contributor to greenhouse gas emissions. Fourth, they can be incorporated as an important part of the nutrient management planning of a farm to prevent nutrient overloading in the soil resulting from manure spreading. Finally, biogas used for power production replaces the use of fossil fuels for the same purpose.

Kauai Outlook

Opportunities for utilization of biogas produced by anaerobic digestion on Kauai are poor. Kauai does not have sufficient concentrated animal farming activities that would make animal manure digestion attractive. According to the Statistics of Hawaii Agriculture, most of the approximately 10,000 cattle raised on the island are for beef production, with less than 50 cows for dairy production. Further, there are only about 2,000 pigs raised on the island.[9] This quantity and density of animals is insufficient for economical power production.

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[9] Hawaii Department of Agriculture and US Department of Agriculture, "Statistics of Hawaii Agriculture, 2000", available at: http://www.nass.usda.gov/hi/stats/t_of_c.htm, March 2004.

The prospects for power generation from biogas produced at local wastewater treatment plants are also minimal. Kauai has four public wastewater treatment plants, all relatively small (the highest average flow is at Lihue, 1.2 million gallons per day). According to Mel Matsumura of the County, there is little potential for biogas utilization. For example, biogas production at the Lihue treatment plant is flared with a small "candle-like" flame. Apparently the County had been approached by a biogas developer in the past, but after visiting the site, the developer did not make contact with the County again. Most new housing and resort developments on the island are served by private water and wastewater systems, reducing the possibility that there will be a significant developable resource in the future.[10]

3.2.2 Landfill Gas

Landfill gas (LFG) is produced by the decomposition of the organic portion of waste stored in landfills. Landfill gas typically has a methane content between 45 and 55 percent and is considered to be an environmental risk. Political and public pressure is rising to reduce air and groundwater pollution and the risk of explosion associated with LFG. From an energy generation perspective, LFG is a valuable resource that can be burned as fuel by reciprocating engines, small gas turbines or other devices.

LFG was first used as a fuel in the late 1970s. Since then, LFG collection and utilization technology has steadily improved. LFG energy recovery is now regarded as one of the more mature and successful of the waste to energy technologies. There are more than 600 LFG energy recovery systems in 20 countries.

Applications

LFG can be used to generate electricity and process heat or may be upgraded for pipeline sales. The major constituents released from landfill wells are carbon dioxide and methane. LFG contains trace contaminants such as hydrogen sulfide and siloxanes that should be removed prior to combustion.

Power production from LFG facilities is typically less than 10 MW. As discussed earlier, several types of conversion devices can be employed to generate electricity from LFG. Typically the equipment requires only minor modification so long as the gas is properly cleaned and prepared. Internal combustion engines are by far the most common generating technology choice. About 75 percent of landfills that generate electricity use engines.[11]

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[10] Mel Matsumura (Chief Engineer Kauai County Wastewater Division), personal communication, June 16, 2004.

[11] EPA Landfill Methane Outreach Program.

Depending on the scale of the gas collection facility, it may be feasible to generate power via a combustion turbine and/or a steam turbine. Testing with microturbines and fuel cells is also underway, although these technologies do not appear to be economically competitive for current applications (see Section 3.10).

Resource Availability

Gas production in a landfill is primarily dependent upon the depth of waste in place, age of waste in place, and amount of precipitation received by the landfill. Each landfill is unique because each has a different volume, receives a different amount of water, and has a different material composition. This variability makes it important to measure the quantity and quality of LFG before installing a power generation system.

In general, LFG recovery may be economically feasible at sites that have more than one million tons of waste in place, more than 30 acres available for gas recovery, a waste depth greater than 40 feet, and the equivalent of 25+ inches of annual precipitation. There are methods of changing both the quantity and quality of the LFG, if required, but doing so will affect the long term gas production. It is particularly important to understand that every landfill will reach a point after closure at which time the LFG production will decrease and eventually diminish below economically viable levels.

Figure 3-5. LFG Well Drilling.

Many existing larger landfills have collection systems to remove leachate and LFG from the landfill to prevent it from infiltrating ground water supplies and causing other nuisance problems. These systems are usually connected to a flare system if there is not a power generation system installed. The flares combust the methane in the LFG.

Such sites are attractive to LFG developers because the resource is generally well known and accessible.

In some cases, the payback period of LFG energy facilities is between 2 and 5 years, especially when environmental credits are available and the gas collection system is already in place. Capital costs are dependent on the conversion technology and landfill characteristics, especially the presence of a gas collection system. The cost of installing a gas collection system at an existing landfill can be prohibitive. Performance and cost estimates for typical LFG projects using reciprocating engines are summarized in Table 3-7.

Table 3-7. Landfill Gas Technology Characteristics.

Performance	
Typical Duty Cycle	Baseload
Net Plant Capacity, MW	0.2-15
Capacity Factor, percent	70-90
Economics	
Capital Cost, $/kW	1,700-3,500
Variable O&M, $/MWh	20
Levelized Cost, $/MWh	44-63
Technology Status	
Commercial Status	Commercial
Installed US Capacity, MW	1,100
Kauai Potential	Good, but limited resource

Environmental Impacts

Combustion of landfill gas, as with nearly any other fuel source, does release some environmental pollutants. However, landfill gas to energy systems are generally viewed in a positive light by environmentalists because landfill gas that is otherwise released to the atmosphere is a significant source of greenhouse gas emissions. As a greenhouse gas, methane is 23 times more powerful than carbon dioxide. Collecting the gas and converting the methane to carbon dioxide through combustion greatly reduces the potency of LFG as a source of greenhouse gas emissions.

Kauai Outlook

There is good, but limited potential for LFG on Kauai. Trash generated on Kauai is taken to one central landfill, near Kekaha on the west side of the island. This landfill has been accepting waste since 1953 and was expected to close in 2004, but has recently been given permission to operate until 2009. One cell of the landfill is already closed and capped, with one remaining active cell. The landfill does not have an existing gas collection and flaring system. The US EPA Landfill Methane Outreach Program (LMOP) recently completed a feasibility study of the landfill for the County.[12] The study estimated a 15-year sustainable power production of 0.7 MW at a production cost of 7.8 cents/kWh. However, there are a number of factors that impact these findings. The feasibility study was based on landfill closure in 2004. Additional waste accumulated during the extended operating period will increase landfill gas production potential to perhaps 1 MW. Annual energy generation potential from the larger facility could be expected to be about 7 GWh/yr. The production cost estimate is based on private ownership and the smaller facility size. Finally, it is uncertain if the study authors considered the higher construction and operating costs of power production facilities in Kauai versus the mainland. Additional study on these topics would be warranted if biogas passes the screening phase. The developable potential for landfill gas is summarized in the following table.

Table 3-8. Developable Potential from Landfill Gas.

Year	Energy, GWh	Capacity, MW	Notes
3	3.5	0.5	Assumes development of half of Kekaha landfill
5	7.0	1.0	Assumes full development of Kekaha landfill potential
10	7.0	1.0	
20	7.0	1.0	Additional LFG may be available from future landfills, however, this will likely just offset the expected decline of Kekaha

3.3 Biofuels

Biofuels – liquid fuels derived from biomass – are increasingly gaining acceptance for transportation and power generation purposes. The two most common biofuels used today are ethanol and biodiesel. Ethanol is generally a supplement for gasoline, while biodiesel displaces diesel. The table below introduces some of the key characteristics of the fuels and contrasts them with conventional fuels. This section describes the two fuels in further detail.

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[12] SCS Engineers for US EPA, "Landfill Gas Utilization Feasibility Study Kekaha Landfill", April 2004.

Table 3-9. Domestic Fuel Production and Price Comparison.

	Gasoline	Ethanol	Diesel	Biodiesel
Production Capacity, Mbbl/day	8,853	0.12	538	0.004
Energy Content, Btu/gal (HHV)	124,000	84,000	139,000	128,000
National Average Price, $/gallon	$1.28	$1.75	$1.23	$2.23
National Average Price, $/MBtu	$10.00	$21.00	$9.00	$17.00

Production Source: DOE

Pricing Source: Energy Management Institute, *Alternative Fuels Index*, July 29, 2004. Pricing does not include taxes, rebates, or subsidies.

3.3.1 Ethanol

Ethanol, also called ethyl-alcohol or grain alcohol, is an alcohol that can be easily produced from common agricultural feedstocks such as corn and sugarcane. While ethanol has been widely used in a variety of non-energy related industries for many years, its favorable characteristics as a cool-burning, clean, renewable fuel have recently caused energy applications to dominate ethanol consumption and drive ethanol production in the United States.

Ethanol is most commonly produced through a dry milling procedure. The biomass feedstock is milled to a fine powder and slurried with water. This causes the starch component in the biomass feedstock to break down into its simple sugars (glucose). With the addition of yeast, these simple sugars are then fermented into ethanol. After fermentation, the mash is distilled to 200 proof. To make the ethanol undrinkable as well as to avoid any alcoholic beverage excise taxes, a denaturant (usually gasoline) is added to the ethanol.

Figure 3-6. Ethanol Production Facility in Wisconsin (Source: Badger State Ethanol LLC).

Due to federal legislation, increased demand, and other market drivers, ethanol production has increased dramatically over the last two decades. Production has increased from 50 million gallons in 1980, to 2.81 billion in 2003.[13] Correspondingly, ethanol production facilities are being constructed all across the United States, with most new facilities having a production capacity over 50 million gallons per year. As of 2004, there are 78 ethanol production facilities operating in the United States, and ten new facilities under construction.[14]

Applications

Since ethanol can be used in most spark ignition engines with little to no engine modifications, ethanol use can directly displace gasoline use. Ethanol is already commonly used as a low percentage blend in automobiles; however, recent efforts from the ethanol industry are pushing to market higher percentage ethanol blends such as E85, which contains ethanol as 85 percent of the total fuel volume. In general, ethanol is suitable for any application in which gasoline is used. While this primarily pertains to the transportation sector, there are a variety of power production applications in which ethanol would be a suitable replacement for gasoline or natural gas.

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[13] Department of Energy, Energy Information Administration

[14] American Coalition for Ethanol. (Online) Available at http://www.ethanol.org/production.html. Accessed 3 August 2004.

Resource Availability

While most of the ethanol produced in the United States today is derived from corn, ethanol is also produced from agricultural feedstocks that are high in simple sugars such as sugarcane and sugar beets. Currently, the sugar or starch components of plants are primarily used for ethanol production. It is also possible to utilize the more fibrous parts of biomass, such as the cellulose, hemicellulose polymers, and lignin to produce ethanol. While the sugar polymers in hemicellulose and cellulose are more resistant and difficult to break down using conventional dry milling processes, other production processes are being developed that allow these components to be fully utilized. Researchers have focused their efforts on acid hydrolysis and enzymatic hydrolysis technologies that are capable of breaking down or hydrolyzing the sugar polymers in lignocellulosic biomass such as trees, grasses, and waste biomass. Processes are also under development that gasify organic feedstock (including municipal waste) and synthesize ethanol from the product gas. These alternative processes hope to expand the biomass resource base and lower feedstock cost in ethanol production.

Cost and Performance Characteristics

As a fuel, ethanol has a lower energy density than gasoline, which means that it contains less energy per gallon than gasoline does. The energy content of ethanol is 84,000 Btu/gallon which, when compared to a gallon of gasoline, translates into only 70 percent of the energy per gallon. The price of ethanol is dictated by a complex interaction of the cost of the raw feedstock, the processing technology, state and national subsidies, and the supply and demand for the product. Because of all of these factors, it is not necessarily true that a rise in gasoline prices will make ethanol comparatively cheaper. Nationally, ethanol has recently cost anywhere from $18/MBtu to $25/MBtu, which is $6-$8/MBtu more than gasoline.

Currently the costs of ethanol production using the advanced lignocellulosic technologies are not competitive compared to conventional dry milling and wet milling processes. The high costs are attributed to the high-volume acid requirements. Advancements in acid recovery and recycle will significantly reduce the cost of ethanol production using the lignocellulosic technologies. It has been estimated that such advancements can reduce the cost of ethanol production by up to 40 cents per gallon.

Gasoline and diesel production far outweigh their biofuel counterparts. The market potential for ethanol is greatest in the Midwest, close to the corn feedstock. The difference in price between the Midwest and the West Coast, which has little corn production, can be 20 cents per gallon or more. However, proposed legislation to ban MBTE as a fuel additive and implement new renewable fuel standards, may drastically increase the market potential for ethanol. Ethanol is already used in place of MBTE in many Midwestern states.

Environmental Impacts

Ethanol is a renewable, environmentally friendly fuel that is inherently cleaner than gasoline. Using ethanol reduces emissions of carbon monoxide, particulate matter, oxides of nitrogen, and other ozone-forming pollutants. Ethanol blended fuel can reduce carbon monoxide emissions by as much as 25 percent and greenhouse gas emissions by as much as 35-45 percent.[15]

While the actual energy balance of ethanol was debated for several years, recently released results from a USDA study indicate that corn ethanol yields 67 percent more energy than what is required to produce it.[16] It is further noted that the fossil fuels used in the process of producing ethanol are usually of domestic origin (coal and natural gas), rather than imported fuels. While the USDA's study focused specifically on ethanol produced from corn, it is likely that ethanol production from other feedstocks can yield similar results.

Kauai Outlook

The overall prospects for ethanol in Hawaii are good, particularly for the transportation sector. The state of Hawaii has already implemented a variety of ethanol incentives and is likely to implement further incentives and requirements in the near future. In 2000, Hawaii signed into law an ethanol production incentive providing ethanol producers with a tax credit equivalent to 30 cents per gallon for up to ten years. Further, the state currently provides an exemption from the state's 4 percent excise tax on retail sales for fuels that are at least 10 percent biomass-derived alcohol by volume. In addition to the numerous direct financial incentives from the state for using and producing ethanol, ethanol would directly displace imported petroleum products providing greater resource independence for Kauai.

On Kauai, Gay & Robinson has expressed serious interest in building a 15 million gallon per year ethanol production facility provided the state moves forward with its proposed ethanol content requirement. Ethanol can be relatively easily produced from raw sugar and molasses, or directly from the juices of crushed cane. Gay & Robinson is also investigating the possibility of producing ethanol from excess bagasse. It might be advantageous for KIUC and Gay & Robinson to jointly explore an integrated ethanol

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[15] American Coalition for Ethanol, "Environmental and Clean Air Benefits," available at http://www.ethanol.org/environment.html, accessed 2 August 2004.

[16] United States Department of Agriculture, "Net Energy Balance for Corn Ethanol," available at http://www.bioproducts-bioenergy.gov/pdfs/net%20energy%20balance.pdf, accessed 4 August 2004.

production and power facility that would optimize the production of ethanol from higher value feedstocks, while producing power from waste biomass (such as bagasse).

Although there are many potential feedstocks for ethanol production, sugarcane is one of the most attractive given its high yields and the historical production of the crop on the island. Similar to banagrass discussed earlier, if all 140,000 acres zoned for agriculture on Kauai were used to grow sugarcane yielding 2,070 gallons of ethanol per acre per year, approximately 290 million gallons of ethanol could be produced each year.[17] More realistically, if only 20 percent of this land was available (an amount equal to 28,000 acres, less than the amount of land used for sugarcane in the mid-1990s), about 58 million gallons of ethanol per year could be produced. For comparison, Kauai consumed 32.3 million gallons of gasoline in 2003.[18] Kauai could easily supply 10 percent of its transportation fuel use from ethanol and have remaining fuel for export or other use, including power generation. Assuming power generation from 50 million gallons at a heat rate of 8,000 Btu/kWh (HHV), approximately 525 GWh/yr of energy could be produced from a 75 MW baseload power plant.

Gasoline is generally reserved for use as transportation fuel but can be used for power generation in some applications. Ethanol could be blended relatively easily with gasoline for power applications, if the power conversion technology can burn the blend. Ethanol can also be mixed with diesel; however it has poor solubility and other issues that have limited this application. Further research and development is underway to explore these issues.

It should be noted that for power generation, it is generally more efficient and cost effective to burn the biomass directly rather than convert biomass to ethanol and then burn the ethanol in an engine or turbine. That said, ethanol could be used to displace fuels in existing power plants with minimal modifications to the power plant, similar to solid biomass cofiring (discussed earlier). Given that all of KIUC's existing thermal capacity is designed to burn liquid fuels, this may be attractive; however, there are limitations on which units are compatible. The nearest term application for KIUC would be to replace diesel fuel combusted in the 10 MW thermal steam plant at Port Allen. This would likely require burner modifications to the boiler and some fuel system changes, but these should be straightforward and relatively low cost. Assuming 100 percent firing of ethanol and operation similar to historical patterns[19], this plant would generate about 50 GWh/yr consuming approximately 5.6 million gallons of ethanol. Assuming ethanol is supplied by a third party, this project could be implemented quickly, at low capital cost,

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[17] Yield data from Stillwater Associates, "Hawaii Ethanol Alternatives", available at: http://www.hawaii.gov/dbedt/ert/ewg/ethanol-stillwater.pdf.

[18] State of Hawaii Department of Taxation, "Liquid Fuel Tax Base & Tax Collections", 2003.

[19] 9,000 Btu/kWh (HHV) heat rate and a capacity factor of 60 percent

and with minimal risk to KIUC. On the other hand, its economic viability is strongly linked to the price of diesel compared to ethanol and the future and applicability of ethanol subsidies for power generation.

Other applications utilizing existing KIUC equipment are more complicated. Although it is technically possible to burn ethanol in combustion turbines, manufacturer support of this option has been limited to date. Further, as discussed earlier, mixing ethanol with diesel for reciprocating engines is currently not technically viable. Within a 10 to 20 year timeframe it is likely that these issues may be addressed and additional use of ethanol for KIUC will be limited largely by available supply. Considering these factors, the table below summarizes the developable power potential from ethanol on Kauai.

Table 3-10. Developable Potential from Ethanol for Power Production.

Year	Energy, GWh	Capacity, MW	Notes
3	52.6	10.0	Constrained to use at 10 MW steam plant at Port Allen
5	52.6	10.0	
10	262	37.4	Assumes availability of 25 million gallons per year of ethanol
20	525	74.9	Assumes availability of 50 million gallons per year of ethanol

3.3.2 Biodiesel

Biodiesel is a non-toxic, biodegradable, and renewable fuel that can be used in diesel engines with little or no modification. Biodiesel can be produced from oils and sources of free fatty acids such as animal fat, vegetable oil, and waste greases. Biodiesel is produced by removing excess hydrocarbons from these oils to create a shorter chain molecule that is chemically more comparable to diesel fuel. Sodium methoxide is added to the oil causing the mixture to settle into two simpler constituents: glycerin and methyl ester. The methyl ester is collected, washed and filtered to yield biodiesel. The glycerin has several commercial uses, the most common one being the manufacture of soap.

The actual facilities where biodiesel is created are relatively simple and easily scaled to meet local needs. Two kinds of biodiesel production facilities are in operation today: batch plants and continuous flow plants. Batch plants tend to be much smaller than continuous flow plants, and produce discrete "runs" of biodiesel. Continuous flow plants are usually much larger, run continuously, and are capable of implementing more efficient processes than those used in batch operations. Compared to ethanol, production of biodiesel is still in its infancy. There are very few large scale continuous flow biodiesel plants in operation in the United States at this time.

Applications

Biodiesel can directly displace diesel fuel in many applications. Biodiesel requires some special handling and storage procedures, and is limited to use during warm or temperate seasons/climates due to its viscous nature at low temperatures. No engine modifications are required for most static internal combustion (IC) engine applications. While there has been little study of biodiesel's performance in gas turbine engines, there has been extensive research and testing of the fuel's performance in traditional four-stroke IC engines. As such, biodiesel is already used in a variety of operations throughout the United States.

Biodiesel's greatest market potential lies within the transportation sector. However, diesel is generally the fuel of choice for most IC engine power production, as such, there is substantial potential for biodiesel to replace diesel fuel in the energy sector. A variety of stationary engine products are available for a range of power generation market applications and duty cycles including standby and emergency power, peaking service, intermediate and base load power, and combined heat and power. Reciprocating engines are available for power generation applications in sizes ranging from a few kilowatts to over 5 MW.

Diesel engines have historically been the most popular type of reciprocating engine for both small and large power generation applications. However, in the United States and other industrialized nations, diesel engines are increasingly restricted to emergency standby or limited duty-cycle service because of air emission concerns. While biodiesel does improve the emissions of a diesel engine, the improvements are small when compared to the emissions reduction provided by natural gas powered engines.

Resource Availability

The most basic feedstock for biodiesel is vegetable oil, a long chain hydrocarbon. The oil can be derived from a variety of sources including: soybeans, cotton, palm, rapeseed, sunflower seeds, and restaurant waste greases. These feedstocks are generally categorized as virgin (fats and oils that have not been previously used) and recycled (fats, oils, and greases that have been previously used). While recycled feedstocks tend to have lower costs, they are limited by their availability and a variety of socioeconomic factors that may not be completely controllable. Virgin feedstocks are controlled by the available agricultural resources.

In the United States, soybean and corn oil are the two leading vegetable feedstocks for biodiesel production. These two feedstocks are readily available throughout most of the country and can be grown in the large quantities necessary to meet large scale biodiesel production demands. The pork and beef industries dictate the supply of white grease and tallow that is available for biodiesel production. The supply of recycled fats and oils is largely determined by the demand for fried food products, lubricants, and other oil dependent industries. While biodiesel demand has been known to have moderate impacts on corn and soybean production, it is unlikely that increases in the demand for biofuels will significantly impact the supply of animal fats or recycled greases.[20]

Cost and Performance Characteristics

Currently the production cost of biodiesel can range from competitive with diesel, to as much as 2.5 times higher. Because the majority of biodiesel production cost is directly derived from the cost of the plant feedstock, potential for cost reduction is less than that of ethanol. Biodiesel can be more cost effective when produced from low-cost oils (restaurant waste, frying oils, and animal fats), compared to commodity crops.

Integration of biodiesel into the transportation sector has been limited due to the fact that nearly every major diesel engine manufacturer has imposed blend limits on biodiesel for warranted operations. Typically the fuel composition is restricted to a maximum of 5 percent biodiesel (B5). Recently some manufacturers have raised their limits to 20 percent. Some users have elected to run their engines on B100 and other high percentage blends, conceding the manufacturer's warranty coverage; however, this is a risk that few operators are willing to take.

Gasoline and diesel fuel, and their biofuel counterparts ethanol and biodiesel, are quality controlled based on ASTM specifications. The recent establishment of the ASTM biodiesel specification was a major advance for manufacturers who now have an industry-accepted standard for quality. This new standard will likely lend itself to an increase in large-scale biodiesel production, as well as a greater acceptance of the biofuel by diesel engine manufacturers.

While biodiesel can be used in any standard diesel engine with little to no modification to the engine, due to its different properties, such as a higher cetane number, lower volatility, and lower energy content, biodiesel may cause some changes in the

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[20] Agricultural Marketing Research Center, "Biodiesel as a Value-added Opportunity," available at http://www.agmrc.org/energy/info/biodieselopportunity.pdf, accessed 3 August 2004.

engine performance and emissions. These different properties can affect the injection timing and the diesel combustion process causing lower power output. In contrast, biodiesel has a higher concentration of oxygen (by weight) which lends itself to more complete combustion, and biodiesel's higher cetane number provides smoother combustion and less engine noise.

Environmental Impacts

When compared to petroleum diesel, biodiesel offers a variety of benefits. Testing has shown that biodiesel has lower sulfur emissions and particulate emissions than regular diesel fuel. While biodiesel yields significantly lower sulfur emissions, particulate matter, and unburned hydrocarbons, emissions of nitrogen oxides can be higher for biodiesel than diesel depending upon engine configurations. Not only does biodiesel emit few harmful gases when combusted, but in almost every circumstance, fewer greenhouse gases are emitted in the production and transportation of biodiesel than are released in the production, transportation, and refinement of petroleum diesel. In addition to the aforementioned benefits, biodiesel boasts higher full-fuel cycle efficiency, and, in certain niche applications, a lower cost than petroleum diesel

Kauai Outlook

Given Hawaii's high fuel prices and agricultural productivity, biodiesel is especially attractive in the state. Overall prospects for biodiesel in Hawaii are good both in the transportation and power generation sectors. This is evidenced by Pacific Biodiesel, which already has biodiesel production facilities on Oahu and Maui. The company sells biodiesel for $2.315 per gallon on Maui (retail price including all taxes) compared to $2.61 - $2.65 per gallon for regular unleaded and up to $2.85 per gallon for retail diesel (as of July 23, 2004).[21] The Maui plant has been open since 1996 and produces 200,000 gallons of biodiesel annually. The Oahu plant is double the capacity. The feedstock for the plants is used cooking oil and restaurant trap grease. These are the lowest cost resources, but also the most limited.

There are several resources available on Kauai that could provide required feedstocks for biodiesel production. A study completed in 2002 estimated Kauai's recycled grease resources at roughly 800 tons annually, which could be used to produce approximately the same weight of biodiesel.[22] As for animal fats, the current livestock production on the island suggests that there is limited potential to obtain animal fats for

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[21] "Biodiesel Discussion Board", available at: http://biodiesel.infopop.cc/eve, accessed August 2004.

[22] University of Hawaii, Hawaii Natural Energy Institute, "Biomass and Bioenergy Resource Assessment State of Hawaii", available at: http://www.hawaii.gov/dbedt/ert/biomass-assessment.pdf, December 2002.

fuel production. While recycled fats and oils are the most difficult feedstock to process because of their variable content, they are generally inexpensive.

The fat and oil resource is likely too small to consider for power production. Dedicated crops would need to be planted for large scale production. While not currently grown on the island in any significant quantity, oil palm is considered to be one of the best sources of vegetable oil for biodiesel production and could easily be grown as it is well suited for tropical climates. The reported yield of biodiesel from oil palm is 635 gallons per acre annually, which is over 30 times the yield from corn and 13 times the yield from soybeans.[23] One local businessman expects yields to be even higher, around 1,000 gallons per acre per year.[24] If grown on twenty percent (28,000 acres) of Kauai's zoned agricultural lands, about 17.8 million gallons of biodiesel per year could be produced. In comparison, Kauai consumed 2.2 million gallons of diesel for transportation in 2003.[25] Kauai could easily supply a substantial portion of its diesel fuel needs and have a large amount remaining for power production. Assuming power generation from the entire biodiesel supply at a heat rate of 9,000 Btu/kWh (HHV), approximately 240 GWh/yr of electricity could be produced from a 34 MW baseload power plant.

Compared to ethanol, biodiesel can be integrated more easily into KIUC's existing diesel oil fuel supply and power generation infrastructure. Starting with perhaps a 2 percent biodiesel blend, KIUC could gradually increase the percent of biodiesel supplied to its power plants without noticing significant equipment impacts. Alternatively, KIUC could incrementally add B20 capability to selected units until the entire thermal fleet was fueled with a biodiesel blend. This would allow the utility to quantify and monitor biodiesel impacts on plant performance, emissions, and longevity prior to widespread implementation. Regardless, in the near term, biodiesel potential is constrained by the supply of the fuel. It is estimated that only 25 million gallons were sold in the United States in 2003.[26] Large scale biodiesel production on Kauai with oil palm would require significant investment in a new plantation and production facility, an activity that probably could not be expected to be mature for ten years. In the near term, KIUC could meet its needs from smaller producers and imports from other islands. Table 3-10 outlines a potential development scenario for biodiesel power production on Kauai.

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[23] Joshua Tickell, From the Fryer to the Fuel Tank, 2000.
[24] Bill Cowern (Kauai Mahagony), personal communication, June 15, 2004.
[25] State of Hawaii Department of Taxation, "Liquid Fuel Tax Base & Tax Collections", 2003.
[26] National Biodiesel Board, "Frequently Asked Questions", available at: http://www.biodiesel.org/resources/faqs/, accessed August 2004.

Table 3-11. Developable Potential from Biodiesel for Power Production.

Year	Energy, GWh	Capacity, MW	Notes
3	2.4	0.5	B20 blend in one 2.7 MW diesel engine, 50 percent capacity factor, using 0.18 million gallons per year (MGY) of biodiesel
5	7.1	1.6	B20 blend in three 2.7 MW diesel engines, 50 percent capacity factor, using 0.5 MGY
10	85	19.3	B20 blend in all existing thermal plants except Kapaia combustion turbine, 50 percent capacity factor, using 6 MGY
20	239	54.6	Energy potential from 17.8 million gallons per year, 50 percent capacity factor

Apart from power production, one of the most readily deployable opportunities for biodiesel is to establish small scale production operations at agricultural centers on the island, namely farms and plantations. Most farm equipment runs on standard No. 2 diesel fuel, and is capable of running on biodiesel in some blend. With proper information and support, many farmers and agricultural producers on Kauai could easily develop and operate biodiesel production facilities to meet their own fuel needs as well as supplement the fuel supply of the rest of the island. Such an approach might enable development of a larger biodiesel infrastructure through a "grassroots" staged approach to development.

3.4 Waste to Energy

Waste to energy (WTE) technologies can use a variety of refuse types and technologies to produce electrical power. The direct use of municipal solid waste (MSW) and refuse derived fuel (RDF) to generate power are addressed in this section. An emerging technology, plasma arc, is also explored. Landfill gas is also often considered WTE, and this technology was discussed previously.

Economic feasibility of WTE facilities is generally difficult to assess. Costs are highly dependent on transportation, processing, and tipping fees associated with a particular location. Values given in this section should be considered representative of the technology at a generic site.

3.4.1 Municipal Solid Waste Mass Burn

There are currently 65 WTE plants in the United States using mass burn technology to generate electricity. These plants burn MSW in "as-discarded" form, with minimal or no pre-processing of the waste. Waste to energy facilities employing mass burning of MSW were seen in the 1980s as an environmentally sound and cost effective method of handling the problem of diminishing available landfill space in the United States. However, as concerns about environmental pollutants (particularly dioxin) from the plants have risen, opposition to new projects has become increasingly effective. In addition, costs for MSW facilities have often exceeded initial estimates, and communities are left paying for the plants for years. To its credit, the industry has drastically decreased dioxin emissions over the past decade. Nevertheless, since 1996 only one new MSW facility has come online in the United States. That project retrofitted an existing incinerator to generate steam for a turbine generator. The plant is located in Michigan and is shown in Figure 3-7.

Figure 3-7. Central Wayne Waste to Energy Plant.

Converting refuse or MSW to energy can be accomplished by a variety of technologies. The degree of refuse processing determines the method used to convert municipal solid waste to energy. Unprocessed refuse is typically combusted in a water wall furnace (mass burning). After only limited processing to remove non-combustible and oversized items, the MSW is fed on to a reciprocating grate in the boiler. The combustion generates steam in the walls of the furnace, which is converted to electrical energy via a steam turbine generator system. This is similar to coal and biomass furnaces. Other furnaces used in mass burning applications include refractory furnaces and rotary kiln furnaces, which use other means to transfer the heat to the steam cycle or add a mixing process to the combustion. For smaller modular units, controlled air furnaces, which utilize two-stage burning for more efficient combustion, can be used in mass burning applications.

Applications

The avoided cost of disposal is a primary component in determining the economic viability of a waste to energy facility. For this reason, areas where land costs are high and landfills must be sited far from waste sources are the most likely locations for WTE plants. According to the Integrated Waste Services Association, about two-thirds of WTE plants in the US are on the East Coast. The 65 operating mass burn plants have an annual capacity to process 22.1 million tons of waste. Large MSW facilities typically process 500 to 3,000 tons of MSW per day (the average amount produced by 200,000 to 1,200,000 residents), although there are a number of facilities in the 200 to 500 ton per day size range. The average design capacity of mass burn plants operating in the US is about 1,100 tons per day of waste.[27]

Resource Availability

MSW plants are high capital cost projects that require a cheap and abundant fuel source to operate profitably. For this reason, they are typically cited near large population centers or in areas where land is valued at a premium. The average American generates about 4.5 pounds of garbage per day, most of which would otherwise be sent to landfill.[28] Similar to biomass, the cost of fuel transportation is a primary factor in the economics of an MSW plant. New plants are usually not economically viable unless a high tipping fee can be secured.

Cost and Performance Characteristics

Table 3-12 has typical ranges of performance and cost for a facility burning 300 tons of MSW per day. The $50/ton tipping fee represents a fee that would be competitive with current landfill disposal costs. The $90/ton fee considers the "all-in" costs of disposal of waste on the island. The actual fee the facility would charge will likely be the result of political negotiation between the county and KIUC.

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[27] Integrated Waste Services Association, "The 2004 IWSA Directory of Waste-to-Energy Plants", available at: http://www.wte.org/2004_Directory/IWSA_2004_Directory.html, accessed August 2004.

[28] EPA, available at: http://www.epa.gov/epaoswer/osw/basifact.htm, accessed August 2004.

Table 3-12. MSW Mass Burning Technology Characteristics.

Performance	
Typical Duty Cycle	Baseload
Net Plant Capacity, MW	7
Net Plant Heat Rate (HHV), Btu/kWh	17,500
MSW Consumption, tons per Day	300
Capacity Factor, percent	60-80
Economics	
Capital Cost, $/kW	6,500-9,100
Fixed O&M, $/kW-yr	260-455
Variable O&M, $/MWh	20-33
Levelized Cost, $50/ton tip fee, $/MWh	41-132
Levelized Cost, $90/ton tip fee, $/MWh	(54)-37
Technology Status	
Commercial Status	Commercial
Installed US Capacity, MW	2,493*
Kauai Potential	Good, but limited resource

Notes:
* Includes both mass burn and refuse derived fuel plants.

Environmental Impacts

The products of combustion of MSW are similar to those of most organic combustion materials. Particulate matter must be abated and nitrogen oxides can form if the combustion temperature is too high. Unlike coal, the sulfur emissions from MSW are low. One possible emission that is atypical of other fuels is dioxin. The US EPA has ruled that some types of dioxins are carcinogenic. This issue is debated intensely in the scientific community, but MSW plant construction faces opposition in many communities because of it.

An obvious benefit of burning MSW is that it reduces landfill deposits. The bottom ash recovered from a MSW furnace is reduced to one-tenth of its original volume.

Kauai Outlook

Waste to energy plants are gaining renewed interest throughout Hawaii. The potential for power generation from MSW on Kauai is good, but limited. The Kekaha landfill currently accepts over 200 tons per day of waste, and about 80,000 tons annually.[29] This quantity is sufficient to generate about 44 GWh/yr of electricity from a 7 MW plant operating at 70 percent capacity factor. As discussed in the section on landfill gas, plans are in place to close the landfill in 2009. The County has not identified a future landfill site or developed plans to deal with the growing waste stream. The current tipping fee at the landfill is $56/ton. However, this fee does no cover the capital cost of the landfill, which is covered through taxes. The all-in cost for disposal including the capital cost is about $90/ton.[30] A waste to energy facility looks increasingly attractive at such high disposal costs. The development of a waste to energy facility would address the county's disposal issues while generating baseload power from an eligible renewable resource.

The developable potential for MSW mass burn is summarized in the following table.

Table 3-13. Developable Potential from MSW Mass Burn.

Year	Energy, GWh	Capacity, MW	Notes
3	0.0	0.0	Highly unlikely in near term
5	43.8	7.1	Assumes construction of one 300 TPD unit
10	43.8	7.1	
20	65.7	10.7	Assumes addition of a 150 TPD unit

3.4.2 Refuse Derived Fuel

Refuse derived fuel (RDF) is an evolution of MSW technology. Instead of burning the trash in its bulky native form, trash is processed and converted to fluff or pellets for ease of handling and improved combustibility.

To ensure a proper mix of fuel, trash is typically sorted to remove metals, "heavies" and other undesirable materials. The remaining "clean" trash is conveyed to a mulching facility that shreds the material into small pieces. These pieces are delivered as fuel to a combustor. Due to the extensive pre-processing and sorting of the material, RDF facilities are often considered to be more compatible with local recycling efforts than mass burn facilities.

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[29] SCS Engineers for US EPA, "Landfill Gas Utilization Feasibility Study Kekaha Landfill", April 2004.

[30] Troy Tanigawa (Solid Waste Programs Administrative Officer, Kauai County Solid Waste Division), personal communication, June 16, 2004.

Applications

RDF is preferred in many refuse to energy applications because it can be combusted with technology traditionally used for coal. Spreader stoker fired boilers, suspension fired boilers, fluidized bed boilers, and cyclone furnace units have all been utilized to generate steam from RDF. Fluidized bed combustors are often preferred for RDF energy applications due to their high combustion efficiency, capability to handle RDF with minimal processing, and inherent ability to effectively reduce nitrous oxide and sulfur dioxide emissions. In all MSW or RDF boiler types, the boiler tube metal temperature must be kept at a temperature less than 800ºF to minimize boiler tube degradation due to chlorine compounds in the flue gas.

There are 15 operating refuse derived fuel plants in the United States with an annual capacity to process 6.2 million tons of waste. Typical RDF facilities process 500 to 2,000 tons of RDF per day (the average amount produced by 200,000 to 800,000 residents). The average design capacity of RDF plants operating in the US is about 1,330 tons per day of waste.[31]

Cost and Performance Characteristics

Table 3-14 has typical ranges for performance and costs for a 300 ton per day RDF facility.

Environmental Impacts

RDF faces the same environmental opposition as MSW while providing the same environmental benefits. RDF plants are generally viewed as being more compatible with recycling efforts. RDF plants using fluidized bed technology can potentially achieve lower emissions than mass burn plants.

Kauai Outlook

Like MSW mass burn, RDF is a potentially promising option for Kauai. Resource availability and developable potential is essentially the same as was previously discussed in the MSW mass burn section. RDF technology is commercial technology, but has not been used in as many applications due to its higher cost. The technology does allow for greater recovery of recyclable materials and the potential for lower emissions. Finally, an RDF plant could readily burn other biomass fuels, especially if it was based on fluidized bed combustion technology.

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[31] Integrated Waste Services Association, 2004.

Table 3-14. Refuse Derived Fuel Technology Characteristics.

Performance	
Typical Duty Cycle	Baseload
Net Plant Capacity, MW	7
Net Plant Heat Rate (HHV), Btu/kWh	19,300
RDF Consumption, tons per Day	300
Capacity Factor, percent	60-80
Economics	
Capital Cost, $/kW	9,100-11,700
Fixed O&M, $/kW-yr	455-715
Variable O&M, $/MWh	26-39
Levelized Cost, $50/ton tip fee, $/MWh	110-215
Levelized Cost, $90/ton tip fee, $/MWh	5.8-111
Technology Status	
Commercial Status	Commercial
Installed US Capacity, MW	2,493*
Kauai Potential	Good, but limited resource

Notes:
* Includes both mass burn and refuse derived fuel plants.

3.4.3 Plasma Arc Gasification

Plasma arc gasification is a combination of gasification with plasma arc technology. Both are mature technologies, but the integration of the two is relatively new.

Gasification is typically thought of as incomplete combustion of a fuel to produce a fuel gas with a low to medium heating value. Heat from partial combustion of the fuel is also generated, although this is not considered the primary useable product. The primary product of conventional air-blown gasification is a low heating value fuel, typically 15 to 20 percent (150 to 200 Btu/ft^3) of the heating value of natural gas (about 1,000 Btu/ft^3). Combustible components of the gas include carbon monoxide, hydrogen, methane, higher hydrocarbons such as ethane and propane, and tar. The conventional use for this gas is combustion in a boiler to generate steam, although it could potentially be used in higher efficiency engines or combustion turbines if the gas is sufficiently clean.

There are two primary configurations for plasma torches: transferred and non transferred torches. Both configurations use a pair of electrodes across which a large current is applied. An arc, basically manmade lightning, is created when the electricity bridges the gap between the two electrodes. The arc generates temperatures of up to 30,000°F. The transferred torch directly contacts the arc with the material, or a conductor, in the reactor. The non-transferred torch blows a stream of air across the arc inside the torch to produce superheated gas, approximately 5,000°F. This gas provides the thermal input to the reactor that is required to decompose the material. The temperature in the reactor itself is generally around 2,000°F. Plasma arc torches require large amounts of electricity. Depending on the fuel being processed, the facility may not generate net electricity output.

Figure 3-8. Plasma Arc Torch Operating (Source: http://www.zeusgroup.org/applications.html).

Applications

The extreme temperatures produced by plasma torches makes them well-suited for waste remediation applications because the inorganic constituents in the waste that might normally be hazardous are literally melted to form a glassy slag which can be captured in a solid form. This encapsulation of hazardous waste requires significant amounts of energy and has very specialized economical niche markets. Currently, some industry leaders feel that plasma arc disposal of MSW is not economic. An alternate approach to strictly disposing of the MSW with plasma torches is to gasify the MSW and recover the combustible syngas that results from the thermal reaction. There are very few installations worldwide to benchmark against for economic evaluation. These are summarized in Table 3-15.

Table 3-15. Installed MSW Plasma Arc Gasification Projects.

Vendor - Project	Fuel	Commercial Status	Electrical Capacity, MW	Fuel Throughput, tpd
Westinghouse Plasma Corp.				
Yoshii, Japan	MSW	Pilot	--	25
Utashinai, Japan	ASR/MSW*	Commercial	8	165
Mihama, Japan	MSW	Commercial	--	28
Startech Environmental				
Bristol, Connecticut	Variety	Demonstration	--	5
Integrated Environmental Technologies				
APET, Hawaii	Medical waste	Commercial	--	24

Notes:

* Primary fuel intended to be auto shredder residue (ASR). Plant is capable of using MSW for up to 50 percent of volumetric throughput.

Resource Availability

Plasma arc gasification technologies can process the same basic resources as MSW and RDF technologies. However, plasma arc is particularly well suited to handle difficult materials, such as hazardous waste, auto shredder residue, incinerator ash, low-level radioactive waste, and medical waste. The net power export potential (if any) of a plant depends heavily on the resource being processed.

Cost and Performance Characteristics

Objective cost and performance information for plasma arc systems using MSW is difficult to find. Table 3-14 provides cost and performance characteristics based on a 30 MW plasma arc system recently investigated by Black & Veatch.

Table 3-16. Plasma Arc Gasification Technology Characteristics.

Performance	
Typical Duty Cycle	Baseload
Net Plant Capacity, MW	6.6
Net Plant Heat Rate (HHV), Btu/kWh	19,000
MSW Consumption, tons per Day	300
Capacity Factor, percent	60-80
Economics	
Capital Cost, $/kW	7,200-9,100
Fixed O&M, $/kW-yr	260-455
Variable O&M, $/MWh	20-33
Levelized Cost, $50/ton tip fee, $/MWh	39-122
Levelized Cost, $90/ton tip fee, $/MWh	(64)-19
Technology Status	
Commercial Status	Demonstration
Installed US Capacity, MW	0
Kauai Potential	Poor, given technology status

Environmental Impacts

Plasma arc technologies are well-suited for vitrification of waste materials. Extensive documentation of testing shows that the vitreous slag has very low leaching potential, effectively “locking up” contaminants in the solid material. Air emissions are not as well-documented. Technology suppliers claim that the extreme temperatures of the plasma system dissociate any harmful molecular emissions. However, very little discussion of emissions such as mercury can be found. It does not seem that mercury would be captured in the slag because it has such a low boiling point. Conventional MSW mass burn and RDF facilities seem to have achieved compliance with EPA’s emissions limits for dioxins and furans; plasma arc gasification would not seem to offer substantial benefits over those technologies in that respect.

Kauai Outlook

Plasma arc gasification of MSW is a developmental technology that has not gained widespread support, particularly as a power generation technology. There do seem to be some instances in which it can be cost effective, such as in extremely land constrained areas with significant population density. Even in these favorable conditions, the economic viability of plasma arc projects is very subject to technology risk. It is possible that plasma arc gasification of MSW may become commercial in a 10 to 20 year timeframe. In such case, it could be expected to generate approximately the same amount of electricity as MSW and RDF options.

Table 3-17. Developable Potential from Plasma Arc Gasification.

Year	Energy, GWh	Capacity, MW	Notes
3	0	0	Technology not expected to be fully commercial for utility power applications
5	0	0	
10	43.8	7.1	Assumes construction of one 300 TPD unit
20	65.7	10.7	Assumes addition of a 150 TPD unit

3.5 Hydroelectric

Hydroelectric power is generated by capturing the kinetic energy of water as it moves from one elevation to a lower elevation by passing it through a turbine. Often, the water is raised to a higher potential energy by blocking its natural flow with a dam. The amount of kinetic energy captured by a turbine is dependent on the head (distance the water is falling) and the flow rate of the water. Another method of capturing the kinetic energy is to divert the water out of the natural waterway, through a penstock and back to the waterway. Such "run-of-river" applications allow for hydroelectric generation without the impact of damming the waterway. The existing worldwide installed capacity for hydroelectric power is by far the largest source of renewable energy at 740,000 MW.[32]

Applications

Hydroelectric projects are divided into a number of categories based upon size. Micro hydro projects are below 100 kW. Systems between 100 kW and 1.5 MW are classified as mini hydro projects. Small hydro systems are between 1.5 and 30 MW. Medium hydro is up to 100 MW, and large hydro projects are greater than 100 MW. Medium and large hydro projects are good resources for baseload power generation because of the ability to store a large amount of potential energy behind the dam and release it consistently throughout the year. Small hydro projects generally do not have large storage reservoirs and are not dependable as dispatchable resources.

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[32] International Energy Agency, 2002.

An especially attractive hydro resource is the upgrading and modernization of existing facilities, many of which were built more than 30 years ago. Such "incremental" hydro includes unit additions, capacity upgrades, and efficiency improvements.

Resource Availability

Hydroelectric resource can generally be defined as any flow of water that can be used to capture the kinetic energy of its water. Projects that store large amounts of water behind a dam regulate the release of the water through turbines over time and generate electricity regardless of the season. These facilities are generally baseloaded. Pumped storage hydro plants pump water from a lower reservoir to a reservoir at a higher elevation where it is stored for release during peak electrical demand periods. Run-of-river projects do not impound the water, but instead divert a part or all of the current through a turbine to generate electricity. This technique is used at Niagara Falls to take advantage of the natural potential energy of the waterfall. Power generation at these projects varies with seasonal flows.

Figure 3-9. 3 MW Small Hydro Plant.

All hydro projects are susceptible to drought. In fact the variability in hydropower output is rather large, even when compared to other renewable resources. The aggregate capacity factor for all hydro plants in the US has ranged from a high of 47 percent to a low of 31 percent in just the last 5 years.[33]

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[33] Based on analysis of data from Energy Information Administration, *Renewable Energy Annual 2002*.

Cost and Performance Characteristics

Hydroelectric generation is usually regarded as a mature technology that is unlikely to advance. Turbine efficiency and costs have remained somewhat stable; however, construction techniques and costs continue to change. Capital costs are highly dependent on site characteristics and vary widely.

Table 3-18 has ranges for performance and cost estimates for hydro projects. These values are for representative comparison purposes only. Capacity factors are highly resource dependent and can range from 10 to more than 90 percent. Capital costs also vary widely with site conditions. To be able to predict specific performance and cost, site and river resource data would be required.

Table 3-18. Hydroelectric Technology Characteristics.

Performance	
Typical Duty Cycle	Varies with resource
Net Plant Capacity, MW	0.5-10
Capacity Factor, percent	40-60
Economics	
Capital Cost, $/kW	1,700-5,700
Fixed O&M, $/kW-yr	14-29
Variable O&M, $/MWh	3-6
Levelized Cost, $/MWh	36-109
Technology Status	
Commercial Status	Commercial
Installed US Capacity, MW	79,842
Kauai Potential	Moderate

Environmental Impacts

The damming of rivers for small and large scale hydro applications may result in significant environmental impacts. The first issue involves the migration of fish and disruption of spawning habits. Minimum flows must be maintained in the waterway. For reservoir projects, one of the few viable abatements of this issue is construction of “fish ladders” to aid the fish in bypassing the dam when they swim upstream to spawn.

The second issue involves flooding existing valleys that often contain wilderness areas, residential areas, or archeologically significant remains. There are also concerns about the consequences of disrupting the natural flow of water downstream and disrupting the natural course of nature.

More positively, reservoirs resulting from dams can be valuable recreation areas, and dams assist in flood control efforts, thereby preventing economic hardship and loss of life.

Many environmental groups object to the broad definition of hydroelectric resources as renewable. Numerous classification systems for hydro have developed in an attempt to distinguish "renewable" projects. Generally this distinction is based on size, although "low-impact," low-head, and run-of-river plants are also often labeled renewable. Incremental hydro, which generally does not alter water flows any more than the existing hydro project, may also qualify as renewable.

Kauai Outlook

Hydroelectric generation is a fully commercial technology that already makes a significant contribution to the electric supply on Kauai. Hydro resources on Kauai are very good with consistently large rainfall and sharp elevation changes on many parts of the island. On the other hand, Hawaiian stream flows vary considerably throughout the year, making hydro an intermittent, "as available" resource.

There has been considerable opposition to new hydro development on the island in the past 20 years. Several proposed projects, such as a project diverting the Hanalei River, have been strongly opposed by local residents forcing project developers to eventually abandon plans. However, with the recent increase in fossil fuel prices, there appears to be new interest in hydro development on the island, particularly projects involving upgrades to existing plants and addition of generation to agricultural irrigation systems. Such projects have little new impact on important watersheds and would presumably encounter less opposition than past proposals.

It is difficult to develop a precise estimate of the developable hydro potential on the island due to the large variety of different schemes and the environmental and institutional obstacles facing many projects. A recently released broad survey of United States hydro potential performed by INEEL includes estimates of the cost and performance of new and upgrade hydro projects on Kauai.[34] The INEEL database was developed based on information from projects identified and proposed in the past. Although development of all of these sites is highly unlikely, the INEEL projects provide one view of the developable potential for hydro generation on the island. The total potential identified is about 60 MW producing 320 GWh annually. This could be viewed as an upper bound for the hydro potential on the island. See Table 3-19 for a list of the projects.

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[34] Idaho National Engineering and Environmental Laboratory, "Hydropower Equipment Refurbishment or Replacement: Generation Increases and Associated Costs," 2003.

Table 3-19. INEEL Identified Kauai Hydro Development Projects.

Project Name	Steam	Project Type	Net Capacity, MW	Generation, GWh
Upper Wailua	Mahae St., North Fork Wailua River	Run of river	1.3	6.7
Kitano	Haeleele Stream, Kokee Ditch	Gravity diversion (powerhouse on different stream)	1.5	8.0
Waimea	Waimea River	Gravity diversion (powerhouse on different stream)	2.9	15.5
South Fork Wailua River	South Fork Wailua River	Run of river	6.6	35.3
North	Lumahai River	Run of river	6.0	32.1
Hanalei	Hanalei River	Run of river	6.0	32.1
Kokee Water Project	Kawaikoi Stream / Kokee Ditch	Storage	10.0	53.4
Kauai	Wainha River	Storage	25.0	133.6
Totals			**59.2**	**317**

Source: INEEL, 2003.

Assuming that the INEEL identified hydro projects provide at least a proxy estimate of the hydroelectric generation potential on the island, this list was used to estimate the developable potential for the next 3, 5, 10, and 20 years. Through conversations with developers, KIUC, and publicly available information, background information was obtained to determine the general timeframe in which projects such as these could be developed. The table below shows a hypothetical development timeline. The 25 MW "Kauai" project was not included in the developable potential estimates because of likely very strong public opposition to a hydro project of this magnitude on the island.

Table 3-20. Developable Potential from Hydroelectric Resources.

Year	Energy, GWh	Capacity, MW	Notes
3	8	1.5	Development of the Kitano project
5	61	11.5	Development of the Kitano and Kokee projects
10	118	22.3	Development of these and additional sites
20	183	34.3	Development of all INEEL sites, except "Kauai" project

Note: Conceptual only. Hydro development prospects addressed in detail later in this report.

3.6 Ocean Energy

Ocean energy resources can be captured in numerous ways with a variety of technologies. The current areas of research and development are ocean thermal energy conversion (OTEC), wave energy, and tidal energy.

3.6.1 Ocean Thermal Energy Conversion

An OTEC plant uses the temperature difference between warm surface water and cold deep water to generate electricity via a heat engine system. There are multiple configurations under development, but all OTEC facilities operate on the same basic principle. Comparatively warm surface water is used to heat a working fluid to create vapor and drive a turbine generator. Cold ocean water from depths exceeding 3,000 feet is then used to condense the working fluid. When compared to other renewable technologies, one of the largest advantages of OTEC is the capability to provide base load continuous power output.

Applications

In general, researchers have classified OTEC technology into three main groups: closed cycle, open cycle, and hybrid cycle. Most commercial developments plan to use the closed cycle OTEC (CC-OTEC) system, which uses large seawater heat exchangers to boil and condense a working fluid such as ammonia. Open cycle OTEC (OC-OTEC) uses the seawater directly, boiling the warm seawater at very low pressures and using the cold sweater to condense the steam. Hybrid cycle OTEC (HC-OTEC) uses a combination of the two previous systems. Normally the CC-OTEC is first used to generate electricity, and then an OC-OTEC is used to produce desalinated water.

OTEC is currently in active R&D by several organizations and corporations around the world. Most of these facilities are operated by laboratories or research organizations and receive the majority of their funding through grants, research foundations, or federal programs. This section provides an explanation of some of the R&D and demonstration projects that are ongoing.

The Natural Energy Laboratory of Hawaii Authority (NELHA) and the Pacific International Center for High Technology Research (PICHTR) have led the American efforts in OTEC technology. In 1979 a mini CC-OTEC plant off Keahole Point (Big Island of Hawaii) produced 18 kW of net power. In the 1990's an OC-OTEC plant produced up to 103 kW of net power. No OTEC facility is currently generating at these locations. Research into OTEC and its potential related services continues at NELHA, and a proposal is currently being developed for submittal to NELHA for a 1 MW OTEC plant running on the Kalina cycle.

Ocean Engineering & Energy Systems International (OCEES) based in Honolulu has incorporated the Kalina cycle into their CC-OTEC technology. The Kalina cycle is a modified Rankine cycle with an increased efficiency resulting from the altered properties of its ammonia/water working fluid, rather than the pure water or ammonia working fluid in a standard Rankine cycle. Use of this cycle should allow higher efficiency and hence reduced costs. Figure 3-10 shows a flow diagram of a Kalina Cycle CC-OTEC.

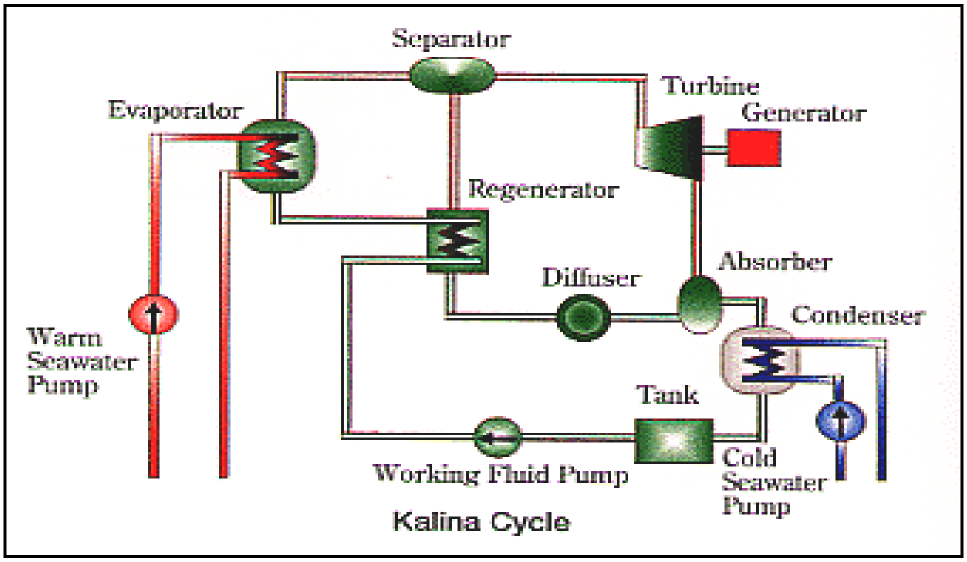

Figure 3-10. CC-OTEC Using the Kalina Cycle (Source: Saga University).

OCEES has partnered with Makai Ocean Engineering who was involved in the recent installation of the new large deep water pipelines at NELHA. OCEES has proposed an 8 MW OTEC plant at the US Navy base on the Diego Garcia Island, Indian Ocean. This project is under active development.

Sea Solar Power International (SSP) has been developing CC-OTEC with funding from the Abell Foundation. They have proposed a 10 MW plant on Guam, and several 100MW floating plants, but were unsuccessful in obtaining financing. They are now proposing a CC-OTEC 10 MW plant for the Cayman Islands using propylene as the working fluid. This appears to be fully funded by the Abell Foundation. This plant is expected to produce 10 MW of net power and 3 million gallons of desalinated water per day.

OTEC plants allow a wide range of other services to be derived from the supply of cold deep ocean water including desalinated water, air conditioning and industrial cooling, aquaculture, and chilled soil agriculture. Many of the current approaches to commercializing OTEC utilize the added-value that these services can bring for a small incremental increase in cost. Since air conditioning and aquaculture can generally only use a small amount of the water required for the OTEC plant, the main added-value service is normally desalinated water.

Resource Availability

OTEC requires warm ocean surface water and cold deep ocean water with a temperature difference exceeding 36ºF. Water cold enough to provide the required temperature difference is normally only found at depths of over 3,000 ft. Further, surface water temperature requirements limit development to tropical oceans. Land-based applications require steep underwater slopes to minimize the length of cold water piping. The use of off-shore OTEC facilities expands the number of suitable locations for development.

Cost and Performance Characteristics

In general, OTEC plants must be large to be economic, which has made financing difficult for developers as there are no large demonstration plants to provide real-world data on costs. The World Bank determined that a pilot plant of 5MW operating for 5 years would be required before the funding risks associated with a large scale plant (50MW) could be justified. Therefore, developers are concentrating on pilot scale plants that are located in niche markets where the price of electricity (and often desalinated water) is high. Table 3-21 presents the estimated performance and costs for an on-shore and off-shore CC-OTEC facility. There is a broad range for the cost estimates, as there has not been a large-scale facility built to test the cost estimates.

Table 3-21. Ocean Thermal Energy Technology Characteristics.

	On-Shore	Off-Shore
Performance		
Typical Duty Cycle	Baseload	Baseload
Net Plant Capacity, MW	10	100
Capacity Factor, percent	90	90
Economics		
Capital Cost, $/kW	13,000-19,500	3,300-6,500
Variable O&M, $/MWh	17-33	17-33
Levelized Cost, $/MWh	140-220	53-103
Technology Status		
Commercial Status	Initial Demonstration	Development
Installed US Capacity, MW	0	0
Kauai Potential	Good	Good

Environmental Impacts

There remain some important questions about the environmental impacts of OTEC plants. The most frequently raised points are: changes to thermal, salinity, and nutrient gradients within the vicinity; leakage of working fluid from CC-OTEC plants or of the chlorine used for controlling bio-fouling; fatalities of small organisms such as plankton; and the effects on fishing grounds.

Kauai Outlook

Several demonstration plants are currently under development, and these should result in significantly more detailed and reliable cost and performance information within the next five years. Commercial application of OTEC by utilities is unlikely until after this time, but Hawaii is then a prime candidate for OTEC. Hawaii has some of the best OTEC resources in the world. Current OTEC technology is not cost completive with conventional power generation technologies; however, with continuing research and demonstration, as well as added value services such as desalination and air conditioning, this technology could become competitive in the long-term.

There have been no numerical estimates of the ocean thermal energy potential in Hawaii; however, the potential is known to be very large and could easily support all of the energy needs of the state.[35] Based on bathymetric data, on-shore plants could be located on the southwest and southeast coasts of Hawaii, on the south coast of

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[35] State of Hawaii DBEDT, http://www.hawaii.gov/dbedt/ert/otec_hi.html, accessed July 2004.

Kahoolawe, and on the southeast coast of Maui. Large offshore plants could be located around any of the islands. The following table summarizes the potential for OTEC in Kauai over the next 20 years.

Table 3-22. Developable Potential from Ocean Thermal Energy Conversion.

Year	Energy, GWh	Capacity, MW	Notes
3	0	0	Technology not expected to be fully commercial for utility power applications
5	0	0	
10	> 500	> 80	Sufficient potential to supply all of Kauai's electricity
20	> 500	> 80	

3.6.2 Wave

The power of ocean waves can be harnessed using a wave energy conversion system (WECS). Many hundreds of WECS technologies have been suggested; only a very small proportion of these have been evaluated beyond the concept stage, and of those only a limited number have been developed beyond laboratory testing to deployment as prototypes in real sea conditions. Most of the development work is being performed in Europe, although there is work ongoing in the US, India, Australia, and the Far East countries.

Applications

WECS are generally categorized as shore-based (onshore and near-shore) or offshore systems. There are two basic shore-based wave energy designs: oscillating water column (OWC) devices, and overtopping-tapered channel (TAPCHAN) devices. Examples of these two shore-based technologies are shown in Figure 1.

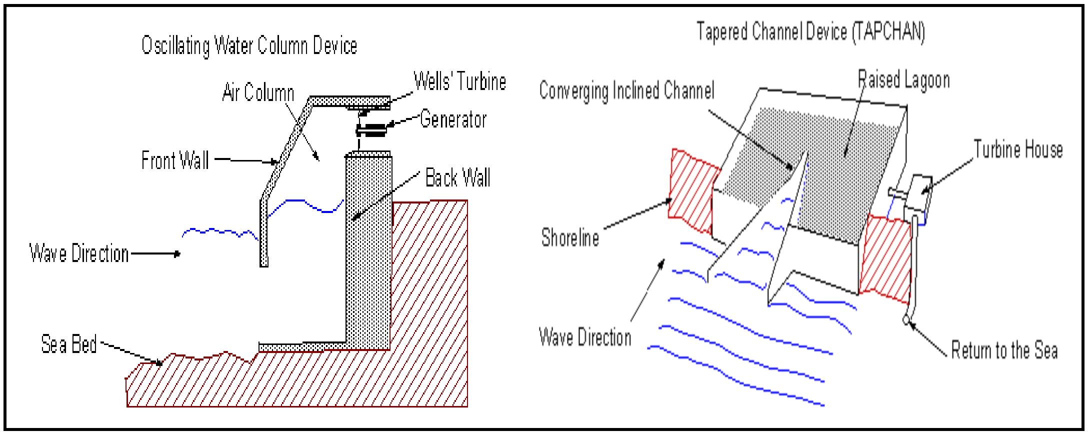

Figure 3-11. Onshore Wave Energy Devices (Source: EU's Atlas Project).

Oscillating Water Column devices generate electricity from the wave-induced rise and fall of a water column. The energy in this water column is normally extracted via a moving air column using an air turbine. The main disadvantage with onshore devices is that their construction is very dependent on local conditions and the available wave power is lower at the shoreline; the advantage is that power transmission and maintenance access are much simpler. The most developed example is Wavegen's 500 kW LIMPET device operating since 2001.

Near-shore devices that can often be built around existing breakwater structures include the Energetech device that uses a parabolic wall to focus wave energy onto the collector and a Dennis-Auld turbine. In general, near-shore devices have the advantage that they can access higher wave power without the need for extensive electricity transmission, however (as with onshore devices) their shoreline location may affect their adoption due to their visual appearance.

Overtopping tapered channel (TAPCHAN) devices generate electricity using conventional low head hydropower turbines. A tapering channel concentrates and funnels waves up the channel and increases their height so that they then spill into the reservoir. As these are driven by water flowing from a reservoir back to the sea, this device produces a more stable power output. Onshore devices normally need a tidal range of less than 3 feet, deep water near the shore, and a reservoir location.

There is a much greater diversity of offshore WECS. The most common offshore WECS are: 1) pneumatic devices, 2) overtopping devices, 3) float-based devices, 4) moving body devices. In general, offshore devices can access the highest wave power, but will require extensive power transmission as well as survivability/maintenance requirements based on a more extreme environment.

Pneumatic devices generate electricity using air movement, often using a similar OWC concept to that of shore-based devices. Overtopping devices generate electricity using the same basic methodology as the shore-based versions. Float-based devices generate electricity using the vertical motion of a float rising and falling with each wave. The float motion is reacted against an anchor or other structure so that power can be extracted. Moving body devices use a solid body moving in response to wave action to generate electricity.

Float-based devices are the most common of all proposed designs. The well-developed European designs that are still under development include the recent combination of the IPS Buoy and the Swedish Hose Pump as the AquaBuOY, for which a 1 MW demonstration plant consisting of four 250kW buoys is planned for 2006 at Makah Bay, WA. A fully submerged device is the Archimedes Wave Swing of which a 2 MW prototype was successfully installed in Portugal in May 2004 and is now undergoing trials. Ocean Power Technologies (OPT) is developing the PowerBuoy device, and the first 50 kW unit of a 1 MW demonstration system was installed in June 2004 off Marine Corps Base Hawaii at Kaneohe Bay, Oahu. Another company that has shown interest in Hawaii is SeaVolt Technologies who have developed the Wave Rider device; this has yet to be demonstrated.

Moving body devices use a solid body moving in response to wave action to generate electricity. These are the most complex and sophisticated devices. Several have been under development for many years but few appear close to deployment, with the exception of the Pelamis from Ocean Power Delivery (OPD). The Pelamis is a semi-submerged, articulated structure composed of cylindrical sections linked by hinged joints. Power take-off is via hydraulic rams pumping high-pressure oil through hydraulic motors. A wide variety of tests have been performed including sea trials of a 1:7 model, and a full-scale prototype has been deployed for testing at the European Marine Energy Centre (Scotland).

The AquaBuOY, Archimedes Wave Swing, PowerBuoy, and Pelamis devices are shown in Figure 3-12.

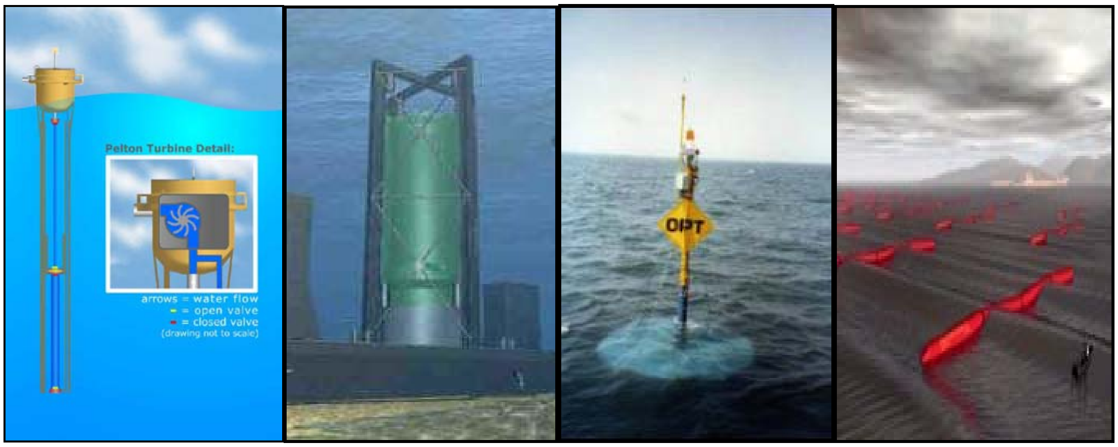

Figure 3-12. AquaBuOY, Archimedes Wave Swing, PowerBuoy, and Pelamis devices. (Sources: AquaEnergy Group Ltd., AWS BV, Ocean Power Technologies, and Ocean Power Delivery).

Costs and Performance Characteristics

Since there has not been large-scale commercialization of any of these technologies, there is a very wide range of predicted costs which are based on theoretical calculations and are therefore highly uncertain. Most onshore devices are likely to be based on OWC technology. The costs of onshore OWC can be estimated from the commercial LIMPET device which has forecast electricity costs of around $100/MWh based on UK wave conditions; given Hawaii's lower wave resource this would probably yield costs of over $200/MWh. Developers of off-shore devices quote costs as low as $30/MWh, but independent studies give likely costs for Hawaii of $150/MWh to $250/MWh. Table 3-23 provides an estimate for a hypothetical 10 MW wave energy plant.

Table 3-23. Wave Energy Technology Characteristics.

Performance	
Typical Duty Cycle	Intermediate
Net Plant Capacity, MW	10
Capacity Factor, percent	40
Economics	
Capital Cost, $/kW	4,600-5,900
Variable O&M, $/MWh	59-78
Levelized Cost, $/MWh	173-225
Technology Status	
Commercial Status	Demonstration
Installed World Capacity, MW	~1
Kauai Potential	Moderate

Environmental Impacts

Wave energy devices are generally considered to be environmentally benign, however there are some concerns including degradation of marine habitat and adverse visual impacts. These concerns may be mitigated through careful siting of projects.

Kauai Outlook

There is currently a high level of development activity on these technologies in Hawaii and around the world. A few technologies are now at full-scale prototype deployment and could be ready for semi-commercial applications, within the next 1-3 years.

The most complete wave energy resource assessment of Hawaii was performed in 1992 in the report entitled *Wave Energy Resource and Economic Assessment for the State of Hawaii.*[36] The study noted that the primary sources of wave energy in Hawaii are sea

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[36] SEASUN Power Systems, "Wave Energy Resource and Economic Assessment for the State of Hawaii", available at http://www.hawaii.gov/dbedt/ert/wave92/wave92.html, June 1992.

build-up from local trade winds and swell generated by extratropical storms in the north Pacific Ocean. There are additional wave producing forces that originate in the southern hemisphere, but these are a minor contribution to the wave energy resource. The analyses for this report found that the wave power density along the 80-m depth contour typically averages 10 to 15 kW/m. This is surprisingly low considering Hawaii's location in the Pacific. The recently released EPRI Innovation Institute *Survey and Characterization of Potential Offshore Wave Energy Sites in Hawaii* notes that the wave energy resource on the northern shores of the Hawaiian Islands far exceeds the electricity demand for all islands, except Oahu.[37]

Hawaii's reasonable wave resource, centers of population close to the coast, and high electricity prices mean that wave energy may have potential for utilities in the near future (5-10 years). However, development will be limited by environmental constraints (particularly visual appearance and any potential or perceived effect on tourism), and utility constraints due to the variability of wave power output. Further, as the industry is still in its formative stages with a limited number of commercial products, potential is limited by the ability of the technology developers to supply the necessary equipment. Based on these considerations, the following table summarizes the potential for OTEC in Kauai over the next 20 years.

Table 3-24. Developable Potential from Wave Energy.

Year	Energy, GWh	Capacity, MW	Notes
3	3.5	1	Constrained by technology supplier ability to provide product
5	17.5	5	
10	175	50	
20	> 500	> 140	Sufficient potential to supply all of Kauai's electricity

3.6.3 Ocean Tidal

The generation of electrical power from ocean tides is very similar to traditional hydroelectric generation. A tidal power plant consists of a tidal pond created by a dam, a powerhouse in the dam containing a turbo generator, and a sluice gate in the dam to allow the tidal flow to enter and leave. By opening the sluice gate in the dam, the rising tidal waters are allowed to fill the tidal basin. At high tide these gates are closed and the tidal

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[37] Electricity Innovation Institute and EPRI "Survey and Characterization of Potential Offshore Wave Energy Sites in Hawaii", available at: http://www.e2i.org/e2i/docs/003_Hawaii_Site_Report.pdf, June 2004.

basin behind the dam is filled to capacity. After the ocean waters have receded, the tidal basin is released through a turbo-generator in the dam. Power may be generated during ebb tide, flood tide, or both.

Resource Availability

Tidal power is typically used as an intermediate generation source for utilities because of the intermittent, although predictable, nature of the tidal resource. The capacity factor of tidal energy facilities may be expected to be around 25 percent. A few utility-scale facilities have been developed around the world. The largest facilities are a 240 MW plant in France and an 18 MW plant in Canada.

Times and amplitudes of high and low tide are predictable, although these characteristics will vary considerably by region. Economic studies suggest that tidal power will be most economical at sites where mean tidal range exceeds about 16 feet. In the US, these conditions only exist is Maine and Alaska, which precludes the rest of the country, including Hawaii, from the economic generation of power from this resource.

Cost and Performance Characteristics

Costs to develop a tidal energy facility are extremely site-specific, and can vary considerably. Table 3-25 presents a range typical performance and cost characteristics for tidal energy plants.

Table 3-25. Tidal Energy Technology Characteristics.

Performance	
Typical Duty Cycle	Intermediate
Net Plant Capacity, MW	18-40
Capacity Factor, percent	20-25
Economics	
Capital Cost, $/kW	3,300-6,800
Fixed O&M, $/kW-yr	7-33
Variable O&M, $/MWh	1-3
Levelized Cost, $/MWh	140-305
Technology Status	
Commercial Status	Early Commercial
Installed World Capacity, MW	250+
Kauai Potential	Poor

Environmental Impact

Utilization of tidal energy for power generation has the environmental advantage of a zero emission technology. However, the environmental and aesthetic impact that the facility has on the coastline must be carefully evaluated. The main barriers to the increased use of tidal energy are the high cost and long period for the construction of the tidal generating system and concerns about impacts on sensitive estuarine ecosystems.

Kauai Outlook

Tidal energy is a mature renewable energy technology that can provide competitive power prices with ideal tidal conditions. However, tidal resources on Kauai are very poor, with summer and winter height differences in the range of 3 feet.[38] Due to the small tidal changes, development of tidal energy generation facilities would not be possible in Kauai with current technology.

3.7 Solar

Solar radiation can be captured in numerous ways with a variety of technologies. The two major groups of technologies are solar photovoltaic and solar thermal.

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[38] Tide height data obtained from co-ops.nos.noaa.gov

3.7.1 Solar Photovoltaic

Photovoltaics (PV) have achieved considerable consumer acceptance over the last few years. PV module production tripled between 1999 and 2002, reaching a worldwide output of 562 MW in 2002. Worldwide grid-connected residential and commercial installations grew from 120 MW/yr in 2000 to nearly 270 MW/yr in 2002. The majority of these installations were in Japan and Germany, where strong subsidy programs have made the economics of PV very attractive. Large scale (>100 kW) PV installations have been added at a rate of about 5 MW per year over the last 2 years.[39]

PV cells convert sunlight directly into electricity by the interaction of photons and electrons within the semiconductor material. To create a PV cell, a material such as silicon is doped (i.e., mixed) with atoms from an element with one more or one less electron than occurs in its matching substrate (e.g., silicon). By alternate doping, thin layers of "p" material and of "n" material are created to form a "pn" junction. Photons striking the cell cause electrons to be set free in the junction, creating a current as it moves across the junction. The current is gathered through a metallic grid. Various currents and voltages can be supplied through series and parallel cell arrays.

Figure 3-13. Photovoltaic Solar Panel Installation.

The direct current produced depends on the material involved and the intensity of the solar radiation incident on the cell. Single crystal silicon cells are most widely used today. Single crystalline cells are manufactured by growing single crystal ingots, which are sliced into thin cell-size material. The cost of the crystalline material is a significant part of the cell production cost. Other methods of crystalline cell production (casting of polycrystalline material, pulling of cell-thickness ribbons) can cut material costs at some penalty to cell efficiency.

Another approach to reducing cell material cost is the development of thin film PV cells. Commercial thin films are principally made from amorphous silicon; however, amorphous silicon cells suffer significant degradation and are not being seriously developed for large power applications. Copper indium diselenide and cadmium telluride show promise as low-cost solar cells. Thin film solar cells require very little material and can be manufactured on a large scale. Furthermore, the fabricated cells can be flexibly sized and incorporated into building components. However, to date, thin film technology has not proven to be cost effective compared to crystalline silicon.

Gallium arsenide cells are among the most efficient solar cells and have other technical advantages, but they are also more costly. Gallium arsenide cells are typically used where high efficiency is required even at a high cost, such as space applications.

Applications

The modularity, simple operation, and low maintenance requirements of solar PV makes it ideal for serving distributed, remote, and off-grid applications. Most PV applications are smaller than 1 kW, although, larger utility-scale installations are becoming more prevalent. Current grid-connected PV systems are generally below 100 kW. Several larger projects ranging from 1 to 50 MW have been proposed. A 3.4 MW project is under construction in Arizona. This is one of the largest PV installations in the world. Most grid-connected PV applications require large subsidies (50 percent or more) to overcome inherently high initial costs.

Resource Availability

Solar radiation reaching the earth's surface, often called insolation, has two components: direct normal insolation (DNI) and diffuse insolation. DNI, which comprises about 80 percent of the total insolation, is that part of the radiation which comes directly from the sun. Diffuse insolation is that part of the radiation which has been scattered by the atmosphere or is reflected off the ground or other surfaces. All of the radiation on a cloudy day is diffuse. The vector sum of DNI and diffuse radiation is termed global insolation. Systems which concentrate solar energy use only DNI, while non-concentrating systems use global radiation. Most PV systems installed today are flat plate systems that use global insolation. Concentrating PV systems, which use DNI, are being developed, but are not considered commercial at this time.

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[39] Paul Maycock, "PV market update", *Renewable Energy World*, July-August 2003.

Generally, stationary (non-tracking) PV arrays will receive the highest average annual insolation if they are mounted at an angle equal to the latitude at which they are located. To optimize performance for winter, the array may be tilted at an angle equal to the latitude plus 15 degrees. Conversely, for maximum output during summer months the array should be tilted at an angle equal to the latitude minus 15 degrees. Single and double axis tracking systems increase the system output, but at a significantly higher capital cost and increased O&M requirements.

Cost and Performance Characteristics

Numerous variations in PV cells are available, such as single crystalline silicon, polycrystalline, and thin film panels. Several support structures are available, such as fixed-tilt, one-axis tracking, and two-axis tracking. For evaluation purposes, fixed-tilt, single crystalline PV systems are characterized in Table 3-26: a 4 kW residential system and a 50 kW commercial system.

Table 3-26. Solar PV Technology Characteristics.

	Residential	Commercial
Performance		
Typical Duty Cycle	As available, peaking	As available, peaking
Net Plant Capacity, kW	4	50
Capacity Factor, percent	18	20
Economics		
Capital Cost, $/kW	9,400-13,800	8,300-10,500
Fixed O&M, $/kW-yr	59	26
Variable O&M, $/MWh	68	30
Levelized Cost, $/MWh	518-764	397-486
Technology Status		
Commercial Status	Commercial	
Installed US Capacity, MW	212	
Kauai Potential	Niche applications	

Environmental Impacts

A key attribute of solar PV cells is that they are virtually non-polluting after installation. Some thin film technologies have potential for discharge of heavy metals in manufacturing; however, this issue is being adequately addressed through proper monitoring and control. Compared to emissions from conventional fossil fuel technologies, these impacts are generally inconsequential.

Kauai Outlook

The technical potential for solar PV on Kauai is very large. The various microclimates across Kauai significantly impact potential. Based on the limited solar research that has been completed on the island, the southern and southwestern coastal regions of Kauai have the most favorable prospects for solar PV applications. Figure 3-14 is a solar insolation map of the island.

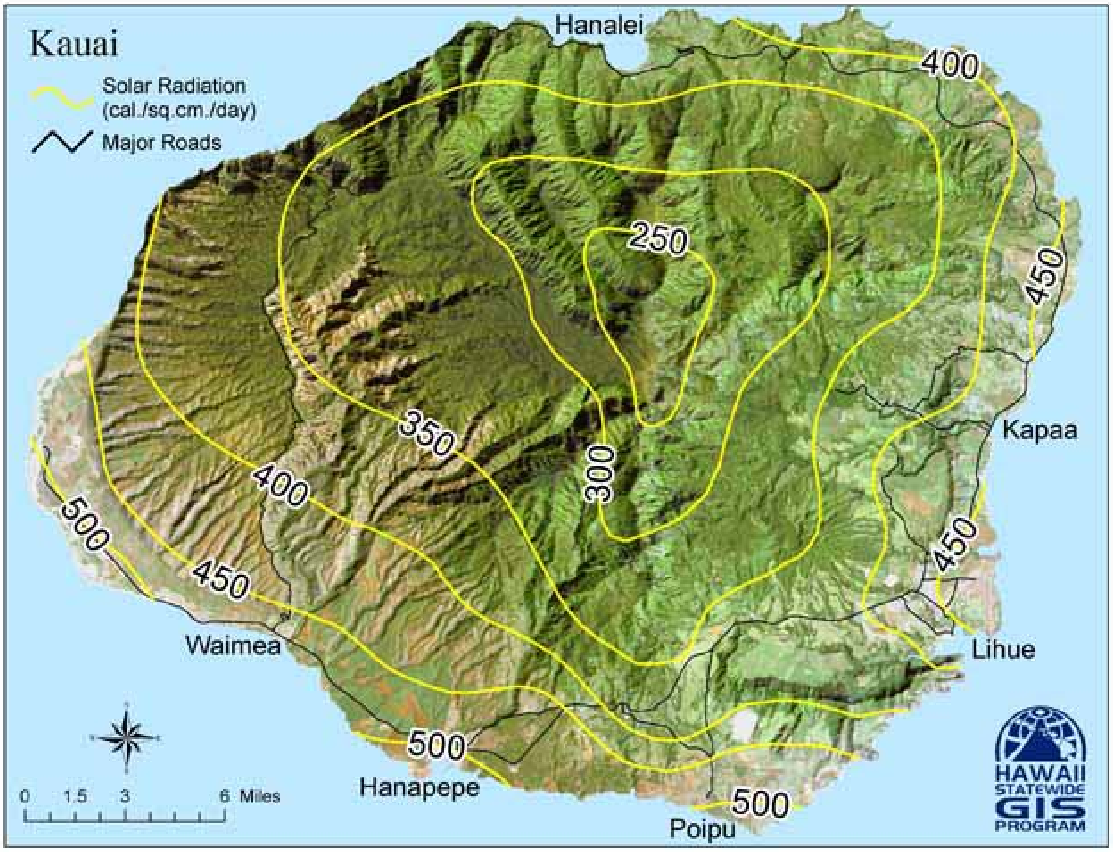

Figure 3-14. Kauai Solar Insolation (Source: Hawaii Statewide GIS Program).

With energy storage, solar could easily supply the entire electricity needs of the island. As an example, using historical solar radiation data from the federal government and the Weather Bureau Army/Navy (WBAN), initial calculations show that a 730 acre solid PV field operating at 11 percent efficiency located in the Barking Sands or Poipu region could generate 500 GWh of electricity per year, which is in excess of the current annual electricity demand. Such a plant would be 285 MW if operated at a 20 percent capacity factor. The land in this area is owned by state, federal, and private owners and is zoned primarily as agricultural or urban land.

It is interesting to note that the land requirements for solar are very reasonable compared to the requirements for other resources. For example, to supply the same amount of energy, a power plant fueled with banagrass would require crop production on over 20,000 acres. Further, oil palm would need to be grown on around 60,000 acres to generate the same energy from biodiesel. Conversely, solar is still several times more costly per kilowatt hour than these options.

Of the suggested regions on the island for solar, Barking Sands has the greatest solar radiation resource coupled with favorable conditions for a large scale PV facility. Further monitoring would be necessary before more accurate generating capacity and design characteristics could be determined.

Given that the solar resource is so large, in the near term, developable solar potential is more limited by the manufacturing capacity of PV module suppliers and the development of suitable energy storage technologies to handle the intermittent output of the resource. Considering these factors, the table below outlines the potential for solar PV on Kauai.

Table 3-27. Developable Potential from Solar Photovoltaics.

Year	Energy, GWh	Capacity, MW	Notes
3	8.8	5	Constrained by technology supplier ability to provide product
5	35	20	
10	53	30	Constrained by intermittency issues
20	> 500	> 285	Sufficient potential to supply all of Kauai's electricity

3.7.2 Solar Thermal

Solar thermal technologies convert the sun's energy to productive use by capturing heat. Early developments in solar thermal technology focused on heating water for domestic use. Advances have expanded the applications of solar thermal to high magnitude energy collection and power conversion on a utility scale. Numerous solar thermal technologies have also been developed over the past three decades as potential sources of renewable power generation. The leading technologies currently include parabolic trough, parabolic dish, power tower (central receiver), and solar chimney.

Figure 3-15. Parabolic Trough Field (Source: Union of Concerned Scientists)

With adequate resources, solar thermal technologies are appropriate for a wide range of intermediate and peak load applications including central station power plants and modular power stations in both remote and grid-connected areas. Commercial solar thermal parabolic trough plants in California currently generate more than 350 MW.

Figure 3-16. Solar Two Central Receiver Installation

Solar thermal systems transfer the heat in solar insolation to a heat transfer fluid, typically a molten salt or heat transfer oil. A steam generator converts the energy in the heat transfer fluid to steam, which is subsequently used to power a turbine. A thermal storage tank can be used to store hot heat transfer fluid, providing thermal energy storage. By using thermal storage or by combining the solar system with a fossil-fired system (a hybrid solar/fossil system), a solar thermal plant can provide dispatchable electric power. Solar thermal technologies may be combined with co-utilization of fossil fuels or energy storage to provide a dependable dispatchable resource.

Solar chimneys do not generate power using a thermal heat cycle as the other three technologies do. Instead, they generate and collect hot air in a large greenhouse. Located in the center of the greenhouse is a tall chimney. As the air in the greenhouse is heated by the sun, it rises and enters the chimney. The natural draft produces a wind current, which rotates a collection of air turbines in the current. The first commercial solar chimney is currently under development in Australia.

Applications

The larger solar thermal technologies (parabolic trough, central receiver and solar chimney) are currently not economically competitive with other central station generation options (such as natural gas combined cycle). Parabolic dish engine systems are small and modular and can be placed at load sites, thereby directly offsetting retail electricity purchases. However, these systems are still under development and have not been used in commercial applications.

Figure 3-17. Parabolic Dish Receiver (Source: Stirling Energy Systems).

Of the four technologies, parabolic trough represents the vast majority of installed capacity, primarily in the US desert southwest. There are nine SEGS (Solar Electric Generating Station) parabolic trough plants in the Mojave Desert that have a combined capacity of 354 MW. These plants were installed from 1985 to 1990 and have been in continual operation since that time. Other parabolic trough plants are being developed, including a 50 MW plant in Nevada. Small parabolic dish engine systems have been developed and are now being actively marketed. These dishes are typically about 25 kW in size. The US government has funded two utility-scale central receiver power plants: Solar One and its successor/replacement, Solar Two. Solar Two was a 10 MW installation near Barstow, California, which is no longer operating due to reduced federal support and high operating costs. A project is proposed in Australia to build a 200 MW solar chimney. The estimated cost is $700 million and would include a chimney one kilometer (0.62 mi) tall with an accompanying greenhouse 5 km (3.1 mi) in diameter.

Resource Availability

Concentrating solar thermal systems (troughs, dishes, and central receivers) use direct normal insolation. Lower latitudes with minimum cloud cover offer the greatest solar concentrator potential. An advantage of solar thermal systems, and all solar technologies generally, is that peak output typically occurs on summer days when electrical demand is high. Solar thermal systems with storage allow dispatch which can improve matching to peaking requirements.

Cost and Performance Characteristics

Representative characteristics for the four solar thermal power plant technologies are presented in Table 3-28.

Table 3-28. Solar Thermal Technology Characteristics.

	Parabolic Trough	Parabolic Dish	Central Receiver	Solar Chimney
Performance				
Typical Duty Cycle	Peaking - Intermediate	As available, Peaking	Peaking - Intermediate	Intermediate - Baseload
Net Plant Capacity, MW	100	1.2	50	200
Integrated Storage?	12 hours	No	16 Hours	Yes
Capacity Factor, percent	40-55	20-25	60-80	60-80
Economics				
Capital Cost, $/kW	5,200-6,500	3,900-5,200	6,500-9,100	4,600-5,900
Variable O&M, $/MWh	33-39	13-26	13-26	13-26
Levelized Cost, $/MWh	133-164	76-91	115-133	87-99
Technology Status				
Commercial Status	Early Commercial	Demonstration	R&D	R&D
Installed US Capacity, MW	~350	< 1	10*	< 1
Kauai Potential	Moderate	Moderate	Moderate	Moderate

* No longer operating

Kauai Outlook

As with solar PV resources on the island, the southern and southwestern regions of Kauai provide the most promising locations for solar thermal applications. Using historical data and geographical information, predictive calculations indicate that a 1350 acre parabolic trough facility operating at 14 percent efficiency could generate 500 GWh of electricity per year, which is in excess of the current annual electricity demand.[40] Such a plant would be 228 MW if operated at a 25 percent capacity factor (no storage), and 114 MW at a 50 percent capacity factor (with storage). Parabolic trough is the preferred technology in the near term, although other technologies offer the promise of greater efficiency once they are proven.

It is unlikely that such a plant could be built in the next three years, but it may be possible in a five to ten year timeframe. The table below indicates the potential of solar thermal on Kauai.

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[40] Efficiency data statistic of National Renewable Energy Laboratory

Table 3-29. Developable Potential from Solar Thermal (Parabolic Trough).

Year	Energy, GWh	Capacity, MW	Notes
3	0	0	Timeframe too short for development
5	> 500	> 114	Sufficient potential to supply all of Kauai's electricity
10	> 500	> 114	Sufficient potential to supply all of Kauai's electricity
20	> 500	> 114	Sufficient potential to supply all of Kauai's electricity

3.8 Wind

Wind power systems convert the movement of the air to power by means of a rotating turbine and a generator. Wind power has been the fastest growing energy source of the last decade in percentage terms and has realized around 30 percent annual growth in worldwide capacity for the last 5 years. Cumulative worldwide wind capacity is now estimated to be more than 39,000 MW. Europe now leads in wind energy, with more than 28,000 MW installed; Germany, Denmark, and Spain are the leading European wind markets. Installations of wind turbines have outpaced all other energy technologies in Europe for the past 2 years.

In the US, the American Wind Energy Association (AWEA) has noted that wind turbine capacity exceeded 6,000 MW at the start of 2004. The booming US wind market has been driven by a combination of growing state mandates, such as that in place for Hawaii, and the production tax credit (PTC), which provides a 10-year 1.8 cent/kWh incentive for electricity produced from wind. The PTC expired at the end of 2003, but was recently extended through 2005. The PTC will apply to new wind projects placed in service by December 31, 2005, unless it is renewed again (for further discussion see Section 6).

Applications

Typical utility-scale wind energy systems consist of multiple wind turbines that range in size from 0.60 MW to 2 MW. Wind energy system installations may total 5 to 300 MW, although single and small groupings of turbines are common in Denmark and Germany. Use of single smaller turbines is also increasingly common in the United States for powering schools, factories, water treatment plants, and other distributed loads. Furthermore, off-shore wind energy projects are now being planned, which is encouraging the development of both larger turbines (up to 5 MW) and larger wind farm sizes.

Wind is an intermittent resource with average capacity factors usually ranging from 25 to 40 percent. The capacity factor of an installation depends on the wind regime in the area and energy capture characteristics of the wind turbine. Capacity factor directly impacts economic performance, thus reasonably strong wind sites are a must for cost effective installations.

Figure 3-18. 9 MW Kahuku Wind Farm on Oahu, Now Decommissioned (Source: DBEDT).

Because wind is intermittent it cannot be relied upon as firm capacity for peak power demands. To provide a dependable resource, wind energy systems may be coupled with some type of energy storage to provide power when required, but this adds considerable expense and is not common. For larger wind farms numerous studies have shown that relatively low levels of wind grid penetration will not necessitate additional backup generation. Efforts are currently underway by research agencies to forecast wind speeds more accurately, thereby increasing confidence in wind power as a generation resource and dependability in utility dispatching.

Resource Availability

Wind speed increases significantly with height above ground. Wind turbine power output is proportional to the cube of wind speed, which makes small differences in wind speed very significant. Wind strength is rated on a scale from Class 1 to Class 7, see

Table 3-30. Wind speeds and power densities (W/m^2) at a Class 1 site and at a 50 m height can go as high as 5.5 m/s and 200 W/m^2. In comparison, wind speeds and power densities at a Class 7 site and at the same hub height may be above 8.80 m/s and 800 W/m^2. Class 4 sites and higher are usually considered the lowest economically viable for wind project development, although Class 3 sites also may be viable in Hawaii. At Class 3 sites, annual average wind speeds may reach 7.0 m/s with a power density of 400 W/m^2 at a 50 m height. Regardless of the existence of high resolution resource maps for some regions, a minimum of one-year of site data collection is typically required to determine if utility-scale wind energy is viable at a specific location.

Table 3-30. US DOE Classes of Wind Power.

Wind Power Class	Height Above Ground: 50 m (164 ft)*	
	Wind Power Density, W/m^2	Speed** m/s
1	0 – 200	0 – 5.60
2	200 – 300	5.60 – 6.40
3	300 – 400	6.40 – 7.00
4	400 – 500	7.00 – 7.50
5	500 – 600	7.50 – 8.00
6	600 – 800	8.00 – 8.80
7	800 – 2000	8.80 +

Notes:

* Vertical extrapolation of wind speed based on the 1/7 power law.

** Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions. To maintain the same power density, wind speed must increase 3%/1000 m (5%/5000 ft) elevation.

Cost and Performance Characteristics

Table 3-31 provides typical characteristics for a 10 MW wind farm and a single 600 kW turbine for distributed applications. Substantially higher costs are necessary for wind projects that require upgrades to transmission and distribution lines.

Table 3-31. Wind Technology Characteristics.

	Wind Farm	Distributed
Performance		
Typical Duty Cycle	As Available	As Available
Net Plant Capacity, MW	10	0.6
Capacity Factor, percent	34-36	20-30
Economics		
Capital Cost, $/kW	1,200-1,600	1,800-2,600
Fixed O&M, $/kW-yr	30-35	35
Variable O&M, $/kW-yr	2-3	
Levelized Cost, $/MWh	44-57	64-88
Technology Status		
Commercial Status	Commercial	
Installed US Capacity, MW	6,352	
Kauai Potential	Good	

Capital costs for new onshore wind projects have remained relatively stable for the past few years. The greatest gains have been made by identifying and developing sites with better wind resources and improving turbine reliability. These both lead to improved capacity factors. The average capacity factor for all installed wind projects in the US has dramatically increased, from just 20 percent in 1998 to more than 30 percent in 2002.[41]

Environmental Impacts

Wind is a clean generation technology from the perspective of emissions. However, there are still environmental considerations associated with wind turbines. First, opponents of wind energy frequently cite visual impacts as a drawback. Turbines are approaching and exceeding 300 feet tall and for maximum production tend to be located on ridgelines and other elevated topography. Combining turbines of different type, manufacturer, color and rotation can increase the visual impact of turbine developments. Second, turbines can cause avian fatalities if they are located in areas populated by native birds or on migratory flyways. To some degree, these issues can be partially mitigated through proper siting, environmental review, and the involvement of the public during the planning process.

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[41] Based on annual wind generation and capacity data from the Energy Information Administration's *Renewable Energy Annual 2002*.

Kauai Outlook

Wind energy is a mature renewable energy technology providing competitively priced power. Wind resources on Kauai are moderate with some areas with very good wind regimes. Recently, detailed wind energy maps have been produced for the island showing wind class at a 200 meter resolution. Figure 3-19 is an adaptation of this data showing Class 3 and higher. Long term data has also been collected for several sites on the island.

Generally, the best wind regimes, up to Class 7, are located on exposed ridgelines, particularly north of Hanapepe and Kalaheo in the south and around the Kalalau valley in the northwest. There is a large region of moderate Class 3-5 winds stretching in a band across the southern portion of the island from Port Allen to Poipu. Because site access is easier and visual impacts will be lower, these resources may be more readily developable than the ridgeline resources. There are also substantial off-shore wind resources in the oceans around Kauai. However, off-shore wind technology deployment is still in its early phases and focused on regions where ocean depth is shallower than the waters off Kauai.

Based on an analysis of the wind class data shown in Figure 3-19, Black & Veatch has estimated the total wind potential available for Kauai. The estimate is made by analyzing the total land area for each of the wind classes, and assigning an assumed MW density per land area, see Table 3-32. The theoretical technical potential of wind on Kauai is generation of 2,450 GWh/yr, which would be produced from over 960 MW of nameplate capacity. This theoretical estimate assumes that all resources on the island could be developed without regard to existing land use, site access, visual impacts, etc. A more realistic long-term upper bound of developable potential is perhaps 20 percent of this number, or 490 GWh/yr. However, in the near term, due to its intermittency and potential grid impacts during low load periods, wind development is likely to be limited to less than 10 MW, which will provide about 30 GWh/yr of energy. More significant development will likely require future integration of additional flexible generation resources, energy storage, and advanced load management.

Table 3-32. Theoretical Kauai Wind Potential.

Wind Class	Land Area of Wind Class, Square Miles	Potential Nameplate Capacity, MW	Potential Annual Generation, GWh/yr
3	55.3	553	1260
4	24.5	245	666
5	7.8	78	234
6	5.4	54	175
7	3.4	34	119
Total	96.5	965	2,450

Table 3-33. Developable Potential from Wind Resources.

Year	Energy, GWh	Capacity, MW	Notes
3	30	10	Limited due to intermittency concerns during low load periods
5	30	10	
10	90	30	Expanded capability due to greater integration with flexible generation and curtailable load, forecasting, and some limited energy storage.
20	490	193	Development on 20 percent of potential land, assuming integration with substantial energy storage resources

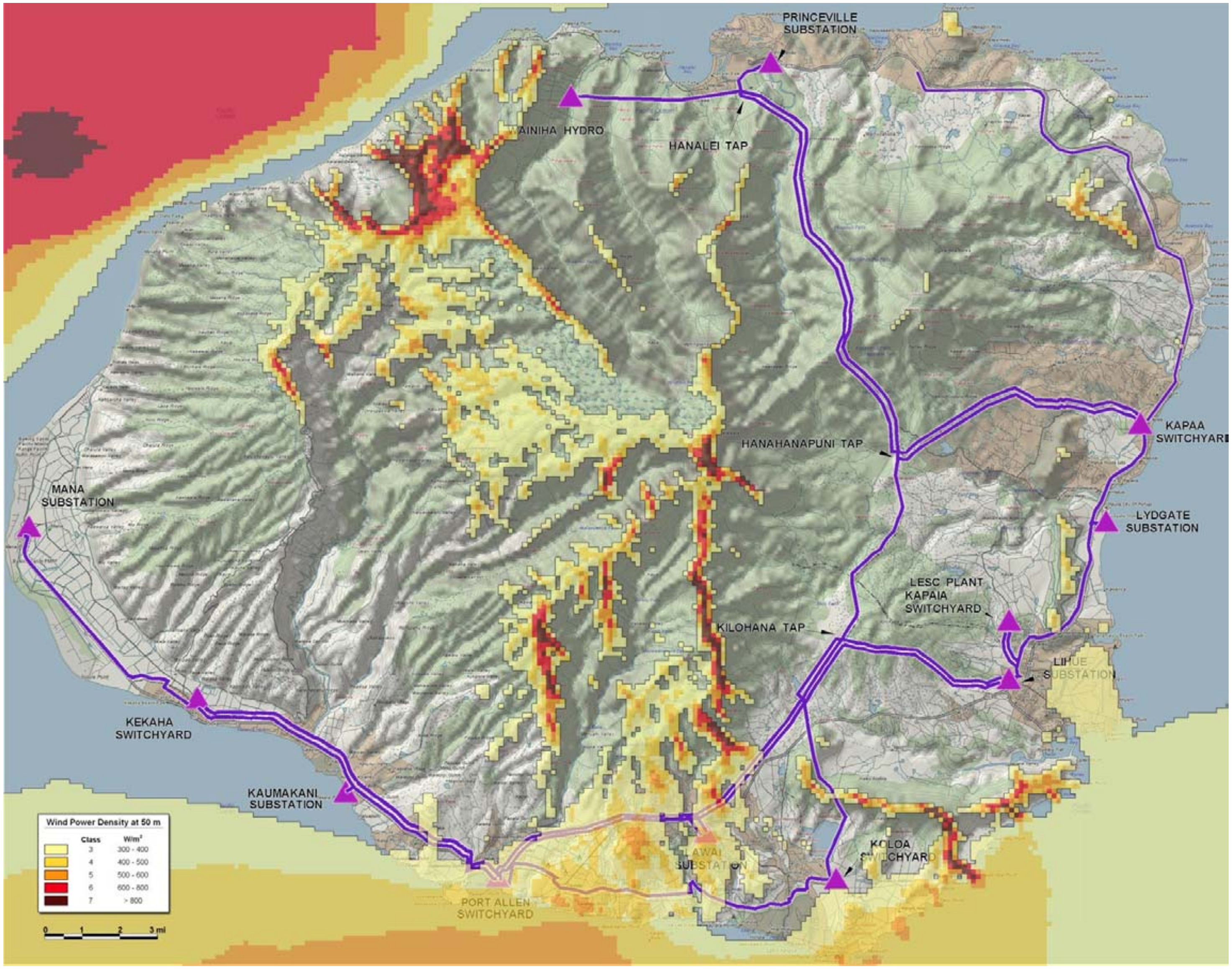

Figure 3-19. Kauai Wind Energy Resources, Class 3 and Above[42].

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[42] Adapted from DBEDT, "Wind Energy Resource Data", available at http://www.hawaii.gov/dbedt/ert/winddata/winddata.html, accessed November 18, 2004.

3.9 Geothermal

Geothermal resources can provide energy for power production or a wide variety of direct use applications. Geothermal power plants use heat from the earth to generate steam and drive turbine generators for the production of electricity. There are three basic types of geothermal technology: dry steam, flash steam, and binary cycle steam. Dry steam power plants are suitable where the geothermal steam is not mixed with water, and operate at high temperatures of between 356º to 662ºF (180º to 350ºC). Flash steam power plants tap into reservoirs of water with temperatures greater than 360ºF (182ºC). Binary cycle power plants operate on water at lower temperatures of 225º to 360ºF (107º to 182ºC).

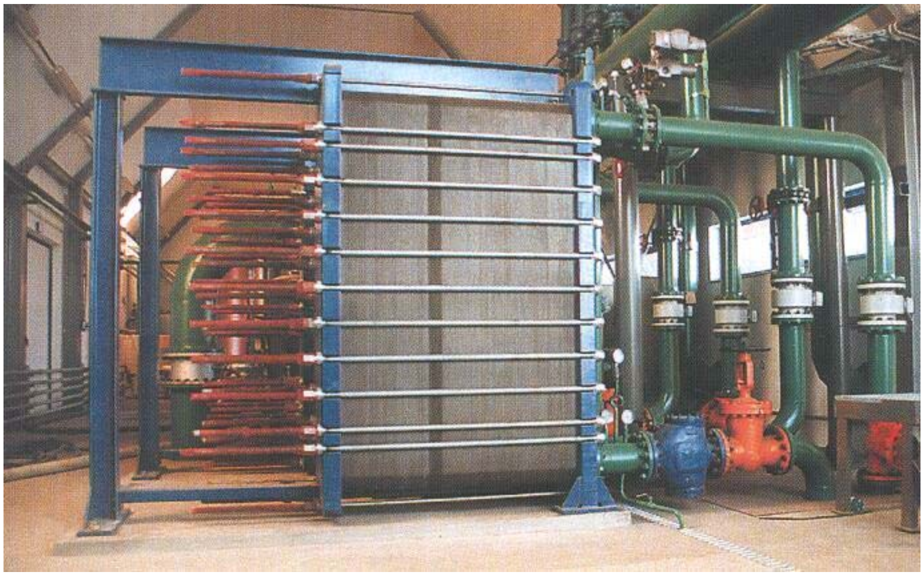

Figure 3-20. Geothermal District Heating Equipment.

As of 2002 the global installed capacity for geothermal power plants was 8,227 MW_e (megawatt electrical). An additional 15,580 MW_{th} (megawatt thermal) was used in direct heat applications. It is estimated that geothermal resources using today's technology could support between 35,500 and 72,000 MW_e of electrical generating capacity. Using enhanced technology that is currently under development (permeability enhancement, drilling improvements) geothermal resources have the potential to support between 65,500 and 138,000 MW_e.[43]

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[43] *Renewable Energy World*, 2002

Applications

In addition to generation of electricity and direct space heating applications, hot water and saturated steam from a geothermal resource can be used for a wide variety of process heat applications such as fish hatching, mushroom growing, refrigeration, washing and drying of wool, drying and curing of light aggregate cement slabs, evaporation in sugar refining, canning of food, drying of timber, and digestion of paper pulp.[44]

Resource Availability

Geothermal power is limited to locations where geothermal pressure reserves are found. Well temperature profiles determine the potential for geothermal development and the type of geothermal power plant installed. High energy sites are suitable for electricity production, while low energy sites are suitable for direct heating.

Cost and Performance Characteristics

For representative purposes, a binary cycle power plant is characterized in Table 3-34. Capital costs of geothermal facilities can vary widely as the drilling of individual wells can cost as much as four million dollars, and the number of wells drilled depends on the success of finding the resource.

Table 3-34. Geothermal Technology Characteristics.

Performance	
Typical Duty Cycle	Baseload
Net Plant Capacity, MW	30
Capacity Factor, percent	70-90
Economics	
Capital Cost, $/kW	3,300-5,200
Fixed O&M, $/kW-yr	260-390
Levelized Cost, $/MWh	84-128
Technology Status	
Commercial Status	Commercial
Installed US Capacity, MW	2,216
Kauai Potential	Very Poor – No Resource

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[44] Geothermal Resources Council, 2003.

Environmental Impacts

Dissolved minerals and hazardous non-condensable gases in geothermal fluids can be an environmental concern if not handled correctly (fluid reinjection addresses many concerns). Geothermal power plants with modern emission control technologies have minimal environmental impact. They emit less than 0.2 percent of the carbon dioxide, less than 1 percent of the sulfur dioxide and less than 0.1 percent of the particulates of the cleanest fossil fuel plant.

There is the potential for geothermal production to cause ground subsidence. This is rare in dry steam resources, but possible in liquid-dominated fields. However, carefully applied reinjection techniques can effectively mitigate this risk.

Kauai Outlook

The prospects for geothermal electricity production on Kauai are poor. In 1995 and 1996 the US Geological Survey (USGS) drilled six groundwater monitoring wells near Lihue that ranged from 800 to 1,150 feet in depth. The results from these monitoring stations yielded water temperatures ranging from 24-27ºC (75-80ºF), practically identical to those in non-geothermal regions of Hawaii.[45] To fully assess the island's geothermal potential, further drilling and investigation would be required. Geothermal resources that might be discovered would likely be more suitable for geothermal heat pumps for building space conditioning and direct heating applications than electricity production.

While several of the other Hawaiian Islands have very promising geothermal potential, as the oldest geological island of the archipelago, Kauai has relatively little to no geothermal activity. While all of the Hawaiian Islands were formed by volcanic activity that took place deep in the Pacific Ocean along tectonic boundaries, the islands formed in a southeastward direction; making Ni'ihau and Kauai the oldest of the islands. This being the case, any significant geothermal activity on the island ceased millions of years ago. As such, there are no promising conventional geothermal resources suitable for power production in Kauai.

3.10 Multi-Fuel Generation Technologies

There are a number of energy conversion technologies that could be used to generate power from conventional and renewable fuels. This section provides a description of each of these technologies, and the outlook for their future implementation.

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[45] GeothermEx, Inc., "Update of the Statewide Geothermal Resource Assessment of Hawaii", available at http://www.hawaii.gov/dbedt/ert/geothermal/geothermex2000.pdf, June 2000.

3.10.1 Reciprocating Engine

Reciprocating engines are well proven prime movers for electric generation, industrial processes, and many other applications. Reciprocating engines operate according to either an Otto or Diesel thermodynamic cycle, very much like a personal automobile. These cycles use similar mechanics to produce work, but differ in the way that they combust fuel.

Operating Principles

Reciprocating engines contain multiple pistons that are individually attached by connecting rods to a single crankshaft. The other end of the pistons seal combustion chambers where fuel is burned. A mixture of fuel and air is injected into the combustion chamber and an explosion is caused. The explosion provides energy to force the pistons down and this linear motion is translated into angular rotation of the crankshaft by the connecting rods. The combustion chambers are vented and the piston pushes the exhaust gases out completing the full rotation of the crankshaft. The process is repeated and work is performed.

Figure 3-21. Engine Generator (Source: Caterpillar Corporation).

Applications

Reciprocating engine generator sets are commonly used for self-generation of power either for emergency backup or peak shaving. However, there is also a well established market for installation of generator sets as the primary power source for small power systems and isolated facilities that are located away from the transmission grid.

When used for power generation, medium speed engines (less than 1,000 rpm), are typically used since they are more efficient and have lower O&M costs than smaller higher speed machines. Efficiency rates for reciprocating engines are relatively constant from 100 to 50 percent load, they have excellent load following characteristics, and they can maintain guaranteed emission rates down to approximately 25 percent load, thus providing superior part-load performance. Typical startup times for larger reciprocating engines are on the order of 15 minutes. However, some engines can be configured to start up and be completely operational within 10 seconds for use as emergency backup power.

Fuel Flexibility

Spark ignition and compression ignition engine generator sets can burn a wide variety of fuels. This list includes diesel, natural gas, biogas, landfill gas, ethanol, propane, naphtha, and biodiesel. Because they have such flexibility, engine generators are well-suited for use as conventional or renewable power generation.

Performance and Cost Characteristics

Table 3-35 provides estimates of performance and costs for a reciprocating engine power station. For reference, the price of fuel is assumed to be $12/MBtu, which is equivalent to diesel at $1.66/gallon.

Table 3-35. Reciprocating Engine Technology Characteristics

Engine Type	Spark Ignition	Compression Ignition (Diesel)
Commercial Status	Commercial	Commercial
Performance		
Net Plant Capacity, kW	1-5,000	1-10,000
Net Plant Heat Rate, Btu/kWh	9,700	7,800
Capacity Factor, percent	30-70	30-70
Economics		
Capital Cost, $/kW	500-1,300	400-1,000
Variable O&M, $/MWh	20-33	20-33
Levelized Cost, $12/MBtu Fuel, $/MWh	193-223	160-188

Kauai Outlook

The reciprocating engine is a proven technology that has been successfully demonstrated in renewable fuels applications. Reciprocating engines are used in nearly all landfill gas and digester gas power generation applications because of the low capital cost, efficiency, and ease of operations and maintenance. There are many potential applications for reciprocating engines with renewable fuels in Kauai.

3.10.2 Combustion Turbine

The first successful combustion turbine was completed in 1903. Over the next forty years, rapid advances were made to improve the technology to make it a viable means of aircraft propulsion. As the technology matured, combustion turbines were adapted to land-based energy generation uses. With the deregulation of the power industry in the 1990s, combustion turbines became the generator of choice for a vast majority of new power projects. Combustion turbines currently have lower capital costs, shorter construction durations and lower operation and maintenance costs than any other large central plant available on the market. The primary constraint to their continued prominence is the current high price of natural gas and diesel fuel.

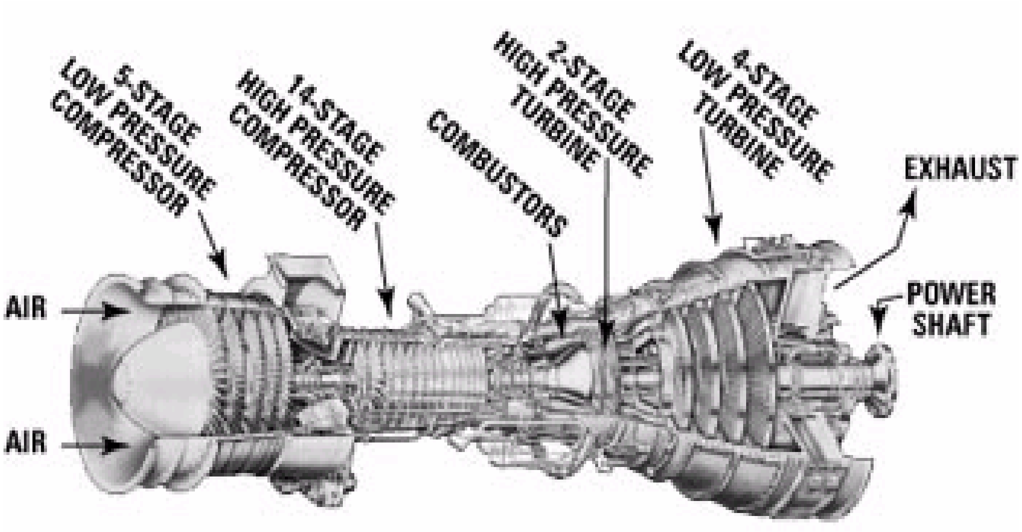

Figure 3-22. Combustion Turbine Section (Source: Langston).

Operating Principles

Power is generated when the combustion turbine compresses ambient air to approximately 12 to 16 atmospheres, heats the pressurized air to 2,000°F or more by burning oil, natural gas or renewable fuels, and then expands the hot gas through a turbine. The turbine then drives both the air compressor and an electric generator. A typical combustion turbine would convert 30 to 35 percent of the fuel energy to electric power, with a substantial portion of the fuel energy exhausted in the form of hot (>900°F) gases exiting the turbine. When the combustion turbine is used to generate power and no energy is captured from the hot exhaust gasses, the power cycle is referred to as a "simple cycle" power plant.

Applications

Simple cycle combustion turbines are the power generation technology of choice for peaking service in the current domestic power industry. Simple cycle technology provides many of the same positive attributes as reciprocating engines, including rapid startup and modularity for ease of maintenance. In addition, combustion turbines have several advantages over reciprocating engines, including lower emissions and lower capital cost.

Fuel Flexibility

Like the reciprocating engine, simple cycle turbines are a conventional technology that can be adapted to burn renewable fuels. Simple cycle turbines can burn natural gas, diesel, propane, biogas and some bioderivative fuels such as biodiesel, ethanol and bio-oil. It should be noted, however, that manufacturers of combustion turbines do not necessarily encourage such fuel flexibility, and burning of alternative fuels may void warranty coverage.

Performance and Cost Characteristics

Generic performance and cost estimates for small simple cycle combustion turbines are listed in Table 3-36. For reference, the price of fuel is assumed to be $12/MBtu, which is equivalent to diesel at $1.66/gallon.

Table 3-36. Simple Cycle Combustion Turbine Technology Characteristics.

Commercial Status	Commercial
Performance	
Net Plant Capacity, kW	300-10,000
Net Plant Heat Rate, Btu/kWh,	11,000
Capacity Factor, percent	30-70
Economics	
Capital Cost, $/kW	700-2,000
Variable O&M, $/MWh	20-33
Levelized Cost, $12/MBtu Fuel, $/MWh	217-256

Kauai Outlook

There is significant potential to utilize combustion turbines with renewable fuels in Kauai. Like engine generators, the simple cycle turbine is a versatile power conversion machine that is well suited for use with a variety of renewable fuels.

Combustion turbines have been successfully used in a number of landfill gas, digester gas, and alternative fuel applications around the world.

The decision between engine generators and combustion turbines usually comes down to size. Combustion turbines are often preferred for applications greater than 5 MW, and engine generators for smaller sizes.

3.10.3 Microturbine

The microturbine is essentially a small version of the combustion turbine. It is typically offered in the size range of 30 to 60 kW. These turbines were initially developed in the 1960's by Allison Engine Co. for ground transportation. The first major field trial of this technology was in 1971 with the installation of turbines in six Greyhound buses. By 1978, the busses had traveled more than a million miles and the turbine engine was viewed by Greyhound management as a technical breakthrough. Since this initial application, microturbines have been used in many applications including small scale electric and heat generation in industry, waste recovery, and continued use in electric vehicles.

Operating Principles

Microturbines operate on a similar principle to that of larger combustion turbines. Atmospheric air is compressed and heated with the combustion of fuel, then expanded across turbine blades which in turn operate a generator to produce power. The turbine blades operate at very high speed in these units, up to 100,000 rpm, versus the slower speeds observed in large combustion turbines. Another key difference between the large combustion turbines and the microturbines is that the compressor, turbine, generator, and electric conditioning equipment are all contained in a single unit about the size of a refrigerator, versus a unit about the size of a rail car. The thermal efficiency of these smaller units is currently in the range of 20 to 30 percent, depending on manufacturer, ambient conditions, and the need for fuel compression; however, efforts are underway to increase the thermal efficiency of these units to around 40 percent.

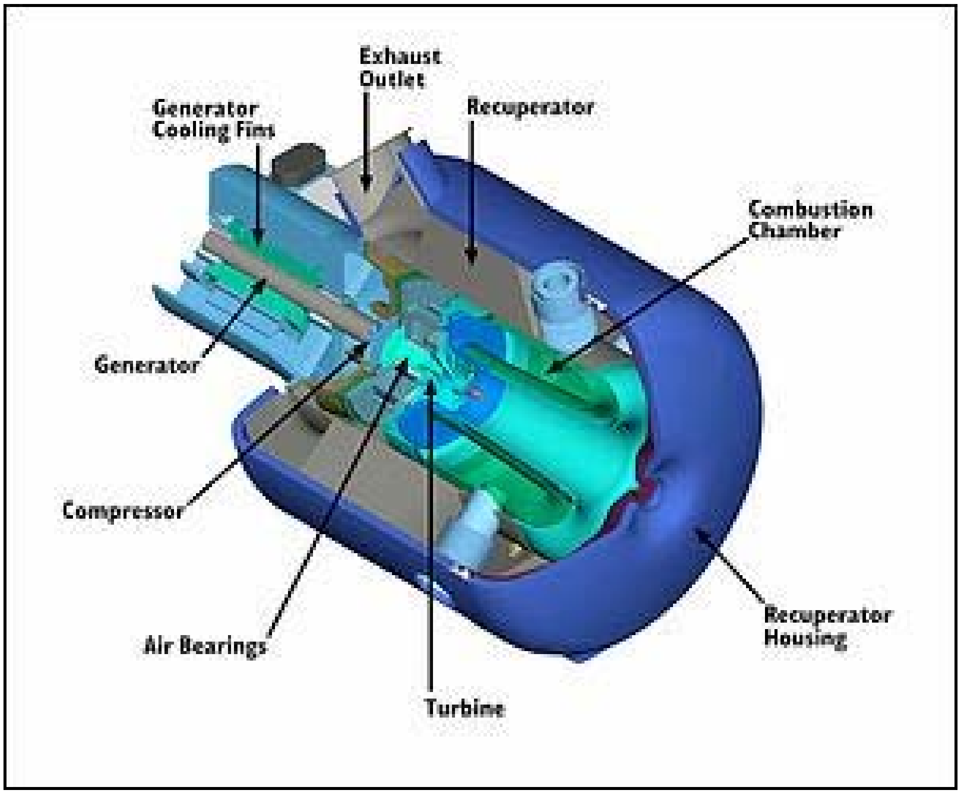

Figure 3-23. Microturbine Cutaway View (Source: Capstone Turbine Corporation.)

Applications

Potential applications for microturbines are very broad, given the fuel flexibility, size, and reliability of the technology. The units have been used in electric vehicles, distributed generation, and resource recovery applications. These systems have been used in many remote power applications around the world to bring reliable generation outside of the central grid system. In addition, these units are currently being used in several landfill sites to generate electricity with landfill gas fuel to power the facilities on the site. For example, the Los Angeles Department of Water and Power recently installed an array of 50 microturbine generators at the Lopez Canyon landfill. The project has a net output of 1,300 kW.

Fuel Flexibility

Microturbines offer a wide range of fuel flexibility, with fuels suitable for combustion including: natural gas, ethanol, propane, biogas, and other renewable fuels. The minimum requirement for fuel heat content is around 350 Btu/scf, depending upon microturbine manufacturer.

Performance and Cost Characteristics

Microturbine costs are often discussed as being about $1,000 per kilowatt. However, this is typically just the bare engine cost. Auxiliary equipment, engineering, and construction costs can be significant. Table 3-37 provides performance and cost characteristics for typical microturbine installations. For reference, the price of fuel is assumed to be $12/MBtu, which is equivalent to diesel at $1.66/gallon.

Table 3-37. Microturbine Technology Characteristics.

Commercial Status	Early Commercial
Performance	
Net Capacity per Unit, kW	15-60
Net Plant Heat Rate, Btu/kWh	12,200
Capacity Factor, percent	30-70
Economics	
Capital Cost, $/kW	1,100-2,000
Variable O&M, $/MWh	13-26
Levelized Cost, $12/MBtu Fuel, $/MWh	234-266

Kauai Outlook

Microturbine technology is in early commercialization. Successful demonstration of the technology has taken place, and there are currently a number of commercial facilities in operation using this technology. Microturbines are often not selected as the power generation technology for landfill gas, digester gas, and renewable fuel applications because of the high capital cost, lower efficiency relative to other conversion technologies, and specialized O&M requirements. There is potential to use this technology on Kauai in the near-term, although other technologies would likely be more economic. In the long-term (10-20 years), if R&D efforts yield efficiency gains and reductions in capital cost, this technology could become a competitive power generation technology.

3.10.4 Fuel Cell

Fuel cell technology has been developed by government agencies and private corporations. Fuel cells are an important part of space exploration and are receiving considerable attention as an alternative power source for automobiles. In addition to these two applications, fuel cells continue to be considered for power generation for permanent power and intermittent power demands. Figure 3-24 shows an example of a fuel cell in operation.

Figure 3-24. 200 kW Fuel Cell (Source: UTC Fuel Cells).

Operating Principles

Fuel cells convert hydrogen-rich fuel sources directly to electricity through an electrochemical reaction. Fuel cell power systems have the promise of high efficiencies because they are not limited by the Carnot efficiency that limits thermal power systems. Fuel cells can sustain high efficiency operation even under part load. The construction of fuel cells is inherently modular, making it easy to size plants according to power requirements.

There are four major fuel cell types under development: phosphoric acid, molten carbonate, solid oxide, and proton exchange membrane. The most developed fuel cell technology for stationary power is the phosphoric acid fuel cell (PAFC). PAFC plants range from around 200 kW to 11 MW in size and have efficiencies on the order of 40 percent. PAFC cogeneration facilities can attain efficiencies approaching 88 percent when the thermal energy from the fuel cell is utilized for low grade energy recovery. The potential development of solid oxide fuel cell/gas turbine combined cycles could reach electrical conversion efficiencies of 60 to 70 percent.

Applications

Most fuel cell installations are less than 1 MW. Commercial stationary fuel cell plants are typically fueled by natural gas, which is converted to hydrogen gas in a reformer. However, if available, hydrogen gas can be used directly. Other sources of fuel for the reformer under investigation include methanol, biogas, ethanol, and other hydrocarbons.

In addition to the potential for high efficiency, the environmental benefits of fuel cells remain one of the primary reasons for their development. High capital cost, fuel cell stack life, and reliability are the primary disadvantages of fuel cell systems and are the focus of intense research and development. The cost is expected to drop significantly in the future as development efforts continue, partially spurred by interest by the transportation sector.

Performance and Cost Characteristics

The performance and costs of a typical fuel cell plant are shown in Table 3-38. A significant cost is the need to replace the fuel cell stack every 3 to 5 years due to degradation. The stack alone can represent up to 40 percent of the initial capital cost. Most fuel cell technologies are still developmental and power produced by commercial models is not competitive with other resources. For reference, the price of fuel is assumed to be \$12/MBtu, which is equivalent to diesel at \$1.66/gallon. A price of \$0/MBtu is also modeled, should a source of waste hydrogen be available.

Table 3-38. Fuel Cell Technology Characteristics

Commercial Status	Development / Early Commercial
Performance	
Net Capacity per Unit, kW	100-250
Net Plant Heat Rate, Btu/kWh	7,000-9,500
Capacity Factor, percent	30-70
Economics	
Capital Cost, \$/kW	6,000-8,400
Fixed O&M, \$/kW-yr*	650-910
Variable O&M, \$/MWh	7-13
Levelized Cost, \$12/MBtu Fuel, \$/MWh	421-589
Levelized Cost, \$0/MBtu Fuel, \$/MWh	308-435

*Notes: Includes costs for cell stack replacement every four years.

Kauai Outlook

Fuel cells are a promising technology that shows potential for clean, renewable, distributed power generation in the future. Continued research and development is required to reduce the capital and O&M cost and increase the fuel cell stack life. In the near-term, fuel cells would be only be competitive with conventional power generation technologies with considerable subsidies, and a low cost (or free) hydrogen fuel source. In the long-term (10-20 years), fuel cells could be a competitive power generation technology, pending advancements in R&D.

There is one potential near-term opportunity to make use of a low cost hydrogen resource on Kauai with fuel cells. TREX makes electronic components at the Pacific Missile Range Facility (PMRF) and produces hydrogen as a waste gas. They are currently producing 16 cfm of hydrogen but will be expanding production soon to produce 40 cfm. The hydrogen is currently flared as waste. The energy value of this hydrogen gas is 0.78 MBtu/hr. At a fuel cell efficiency of 40 percent, this quantity of gas could produce about 90 kW of electricity on a continuous basis. Although this project is small, the economics of it are substantially improved by the zero cost for the fuel. It would also have good demonstration value and could possibly receive grant funding.

4.0 Renewable Energy Technology Screening

This section discusses the technology screening methodology that has been used to evaluate, rank and select Kauai renewable energy resources for further investigation. This section discusses the objective of the methodology, the scoring criteria comprising it, the guidelines for application of the scoring criteria, and the results of the screening process.

4.1 Objective

The objective of the technology screening methodology is to screen and rank technologies for further evaluation. The methodology considers numerous factors affecting project viability including the cost of energy, resource availability, technology maturity, and environmental and socioeconomic impacts. The combination of scores from these and other areas should provide a preliminary indication of the overall viability of potential resources as KIUC investments.

The assessment methodology must be easily applied, yet meaningful. It also must be objective, consistent, and transparent to outside organizations. To meet these goals, Black & Veatch has developed a set of weighted criteria to evaluate and compare projects.

4.2 Screening Criteria

The assessment methodology employs a set of seven criteria. The criteria are given different weights such that 100 total points are possible when the methodology is applied to a given technology. Criteria are specific and measurable to ensure consistent evaluation and quantitative comparison of the final technology scores. The seven criteria are summarized below:

- **Cost of energy** – Assesses the economic competitiveness of the resource. The evaluation is performed based on the levelized busbar cost of generation, which measures the total life-cycle cost of a technology considering capital cost, operating and maintenance cost, capacity factor, and fuel cost (if applicable). Differentiation between various products (firm, as-available, peaking, dispatchable) is assessed in the "Fit to KIUC needs" category.
- **Kauai resource potential** – Indicates the general developable potential of the renewable energy resource in Kauai. There are many methods to determine the technical potential of a particular resource, and literature estimates range considerably. In addition, advancements in technology over time can also

affect estimates of technical potential. For this reason, this evaluation is somewhat subjective and must consider multiple factors.

- **Fit to KIUC needs** – Assesses the fit of the technology to the resource supply needs of KIUC. This criterion considers the scale of the technology, typical generation profile, firm vs. as-available, etc. In the near term, KIUC has sufficient capacity to meet its operating reserve requirements, so firm capacity resources are not preferred.
- **Technology maturity** – Assesses the development status of the technology (commercial, demonstration, R&D, etc.) and the level of technical risk associated with its implementation. Technologies with lower technical risk are given higher scores.
- **Environmental impact** – Assesses the overall environmental impact of the technology. Although renewable energy sources are generally cleaner than fossil fuel power plants, some differentiation can be made among technologies.
- **Socioeconomic impact** – Assesses the overall socioeconomic impact of the technology. Includes factors such as increase in local employment, development of local resources, capacity building, and safety and health impacts.
- **Incentives/Barriers** – Indicates the degree of incentives offered for the renewable resource and barriers against the development of the renewable resource. Incentives may include federal/state subsidies or ancillary benefits of the project, such as addressing solid waste disposal problems. Barriers may include public opposition and other impacts that would raise concerns about the development of the renewable resource.

The weighting factors for the criteria are provided in Table 4-1. Cost of energy accounts for 50 percent of the overall screening score, with the rest of the criteria contributing varying degrees to the remaining 50 percent. Table 4-1 also shows whether criteria also identify a fatal flaw, such as lack of a resource on the island. Finally, some of the scores will change over time as a technology matures or KIUC's needs change in the future. For this reason screening of technologies is done for the next 3, 5, 10 and 20 years.

Table 4-1. Screening Criteria.

Criteria	Weight	Possible Fatal Flaw?*	Time Variant?**
Cost of energy	50		Yes
Kauai resource potential	10	Yes	Yes
Fit to KIUC needs	10	Yes	Yes
Technology maturity	10	Yes	Yes
Environmental impact	7.5		
Socioeconomic impact	7.5		
Incentives / Barriers	5		

Notes:

* Indicates that a failing score for these criteria may result in elimination of the technology from further consideration. For example, lack of geothermal resources on the island eliminates this option from further consideration.

** Indicates that the score may change over time. For example, wave energy technology is currently in the early demonstration phase, but early commercial applications are expected within the next few years.

4.3 Screening Methodology Scoring Guidelines

The assessment methodology was applied by assigning a score from 0 to 100 for each criteria and then applying the weighting factors shown in Table 4-1. The weighted scores are summed to provide the overall project score. Each criterion is scored differently, for example the "cost of energy" and "Kauai resource potential" criteria are largely based on quantitative information. For the remainder of the factors, quantitative data is typically not available, and a qualitative score must be assigned based on available information. Black & Veatch has established individual criteria weighting points and scoring methods as shown in Table 4-2.

Table 4-2. Screening Methodology Scoring Guidelines.

Criteria	Weight	Scoring Details
Cost of energy	50	100 = levelized busbar cost of 5¢/kWh or less 0 = levelized busbar cost of 25¢/kWh or more Proportionately scored between 5 and 25¢/kWh
Kauai resource potential	10	100 = developable potential of 500 GWh/yr or more 0 = developable potential of 5 GWh/yr or less Proportionately scored between 500 and 5GWh/yr
Fit to KIUC needs	10	100 = resource is of appropriate scale, energy production profile matches KIUC needs, and meets KIUC needs regarding dispatchability, capacity vs. energy, etc. 0 = typical project is too large or small, produces energy at unneeded times, and provides product (such as capacity) of little value. Proportionately scored between two extremes
Technology maturity	10	100 = established commercial technology that has been widely adopted. Technology is offered by multiple competitive vendors and fully warranted. 75 = established technology that has been used in several similar applications 50 = early commercial technology that has been successfully demonstrated 25 = emerging technology in the demonstration phase 10 = technology still in research and development 0 = technology concept
Environmental impact	7.5	Relative to other renewable energy technologies: 100 = substantial environmental benefits leading to a cleaner and more sustainable environment 50 = some environmental benefits (base score) 0 = negative environmental effects
Socioeconomic impact	7.5	Relative to other renewable energy technologies: 100 = substantial socioeconomic benefits enhancing the island's economy, health, and general well-being 50 = some socioeconomic benefits (base score) 0 = negative socioeconomic effects
Incentives/ Barriers	5	100 = Significant incentives (e.g., substantial federal subsidy) and no apparent barriers to development. 50 = No significant incentives or barriers 0 = No incentives but substantial obstacles to successful project development

Notes:

* Indicates that a failing score for these criteria may result in elimination of the technology from further consideration. For example, lack of geothermal resources on the island eliminates this option from further consideration.

** Indicates that the score may change over time. For example, wave energy technology is currently in the early demonstration phase, but early commercial applications are expected within the next few years.

4.4 Screening Results

The screening methodology was applied to each of the renewable energy technologies for their potential to contribute to the renewable energy supply within the next 3, 5, 10, and 20 years. The results for each of the criteria are summarized below.

4.4.1 Cost of Energy

The levelized cost of energy is a measure of the total life-cycle cost of a project or technology to generate power. Because the cost of developing a facility can vary considerably, even with modular technologies such as solar photovoltaic or wind energy, a range of project costs and performance assumptions were used to develop levelized cost estimates for each renewable energy technology. The multi-fuel generation technologies were evaluated separately as a fuel has not yet been selected for each of these technologies and the levelized cost of generation is heavily dependent upon the fuel cost. Black & Veatch used the technology cost and performance assumptions developed in the previous section, which are summarized in Table 4-3 for the three year timeframe. The values shown in the table were chosen as representative of the technology application in Kauai.

Of the renewable energy technologies evaluated, wind power has the lowest capital cost per kW installed at $1,200-1,600/kW. This has resulted in a 30 percent annual increase in wind installations worldwide over the last five years. System costs have gone down as single turbines have achieved megawatt sizes. In comparison, conventional biomass and geothermal technologies have capital costs in the range of $2,600-3,900/kW and $3,300-5,200/kW, respectively. The high cost of biomass plants has to do with their relatively small size, extensive fuel and ash handling requirements, and the need for a robust plant design to handle the variability in the fuel quality. Geothermal power plant costs and complexity are highly dependent on the temperature of the geothermal resource, its proximity to the surface and the quality of the brine to be handled. Due to their extensive material handling and emissions control requirements, waste to energy technologies have a substantially higher capital cost than biomass plants, ranging from $6,500 to 11,700/kW. The small size of a potential waste to energy plant in Kauai also increases its relative costs due to economies of scale. Hydroelectric power plants have a wide range of capital costs from $1,700–5,700/kW. Given the turbine technology used for power production is quite mature and costs are low, the civil work that needs to be done to build dams and penstocks tends to be the driving factor behind the capital cost of these systems. Photovoltaic systems are by far the most expensive renewable energy technology with capital costs from $8,300–10,500/kW and a capacity factor of only 20 percent. These systems are currently too expensive to be applied competitively at utility scale. However, they have found a niche in the remote power supply market for rural electrification, water supply, and other applications.

Table 4-3. Renewable Technologies Performance and Cost Summary, Three Year Timeframe.[a]

	Net Plant Capacity, MW	Net Plant Heat Rate, Btu/kWh	Capacity Factor	Capital Cost, $/kW	Fixed O&M, $/kW-yr	Variable O&M, $/MWh	Fuel Cost, $/MBtu	Levelized Cost, $/MWh
Direct Biomass	30	14,500	80	2,600-3,900	78	10	3	114-127
Cofired Biomass	1-50	9,000-12,000	70	100-800	7-26		3	39-64
Anaerobic Digestion	0.085		80	3,000-4,900		20	0	57-77
Landfill Gas	0.2-15		80	1,700-3,500		20	0	44-63
Ethanol	[b]	8,000	65	[b]	[b]	[b]	19-23	206-249
Biodiesel	[b]	9,000	65	[b]	[b]	[b]	15-19	183-232
MSW Mass Burn	7	17,500	70	6,500-9,100	260-455	20-33	-5[c]	41-132
RDF	7	19,300	70	9,100-11,700	455-715	26-39	-5[c]	110-215
Plasma Arc	6.6	19,000	70	7,200-9,100	260-455	20-33	-5[c]	39-122
Hydro	0.5-10		50	1,700-5,700	14-29	3-6		36-109
OTEC (Off-shore)	100		90	3,300-6,500		17-33		53-103
Wave	10		40	4,600-5,900		59-78		173-225
Tidal	18-40		20	3,300-6,800	7-33	1-3		140-305
Solar PV (commercial)	0.050		20	8,300-10,500	26	30		397-563
Solar Thermal (trough)	100		47.5	5,200-6,500		33-39		133-164
Wind (wind farm)	10		35	1,200-1,600	30-35	2-3		44-57
Geothermal	30		80	3,300-5,200	260-390			84-128
IC Engine (spark)[d]	0.001-5	9,700	50	500-1,300		20-33	12	193-223
Comb. Turbine[d]	0.3-10	11,000	50	700-2,000		20-33	12	217-256
Microturbine[d]	0.015-0.06	12,200	50	1,100-2,000		13-26	12	234-266
Fuel Cell[d]	0.1-0.25	7,000-9,500	50	6,000-8,400	650-910	7-13	12	421-589

Notes:

[a] Excludes incentives, subsidies, etc.

[b] Fuel switch Assumed negligible incremental cost for integrating with existing infrastructure.

[c] $50/ton tipping fee.

[d] Multi-fuel technologies included for relative comparison. Generation cost is strongly linked to fuel cost, assumed $12/MBtu.

When comparing the levelized cost of energy produced by these systems, hydroelectric power, landfill gas, biomass cofiring, and geothermal energy all currently produce power at rates competitive with bulk power generation (note that geothermal is not viable on the island). Although these resources have high capital costs, low operating costs combined with high operating capacity factors reduce the overall life-cycle costs. Wind power costs are steadily falling and are significantly lower than costs a decade ago due to increases in wind turbine size and efficiency. Costs for other biomass technologies (direct combustion and anaerobic digestion) are higher given the relatively high capital and operating and maintenance cost of the plants. Direct combustion biomass plants are especially sensitive to fuel cost. This screening section assumes a fuel cost of $3/MBtu, which is higher than most waste biomass fuels (e.g., bagasse) but lower than energy crop fuels. Although waste to energy plants have very high capital costs, high tipping fees can make them economical. The $50/ton tipping fee assumed for this analysis is conservatively low. Ocean and solar technologies are currently expensive, and will likely be reserved for niche applications until costs drop further. Finally, despite requiring minimal incremental capital or operating costs, fuel substitution with ethanol or biodiesel will not be competitive until the costs of these fuels drop below that of their fossil fuel counterparts or adequate financial incentives are offered to cover the higher cost.

Continued improvements will result in improvements in efficiency, capital cost, and operating and maintenance cost for several of the technologies. The technology areas where the levelized cost of power production should come down in the future are wind, photovoltaics, solar thermal, ocean, plasma arc, microturbines, fuel cells, and biofuels. Large improvements are expected for solar photovoltaics and wave energy, with relatively modest improvements in other technologies. These improvements have been included in the forecasts for technology costs beyond the three year timeframe.

The technology specific assumptions and the economic assumptions in Table 4-3 were used to calculate the levelized cost of energy. The calculated average cost of energy for each technology for the next 3, 5, 10, and 20 years is shown in Figure 4-1. The range of costs for the three year timeframe is shown in Figure 4-2. The average levelized cost value was used to provide each technology with a score out of 100, with 100 being lower cost (<$50/MWh), and 0 being higher cost (>$250/MWh). The results of the cost of energy screening are provided in Table 4-4.

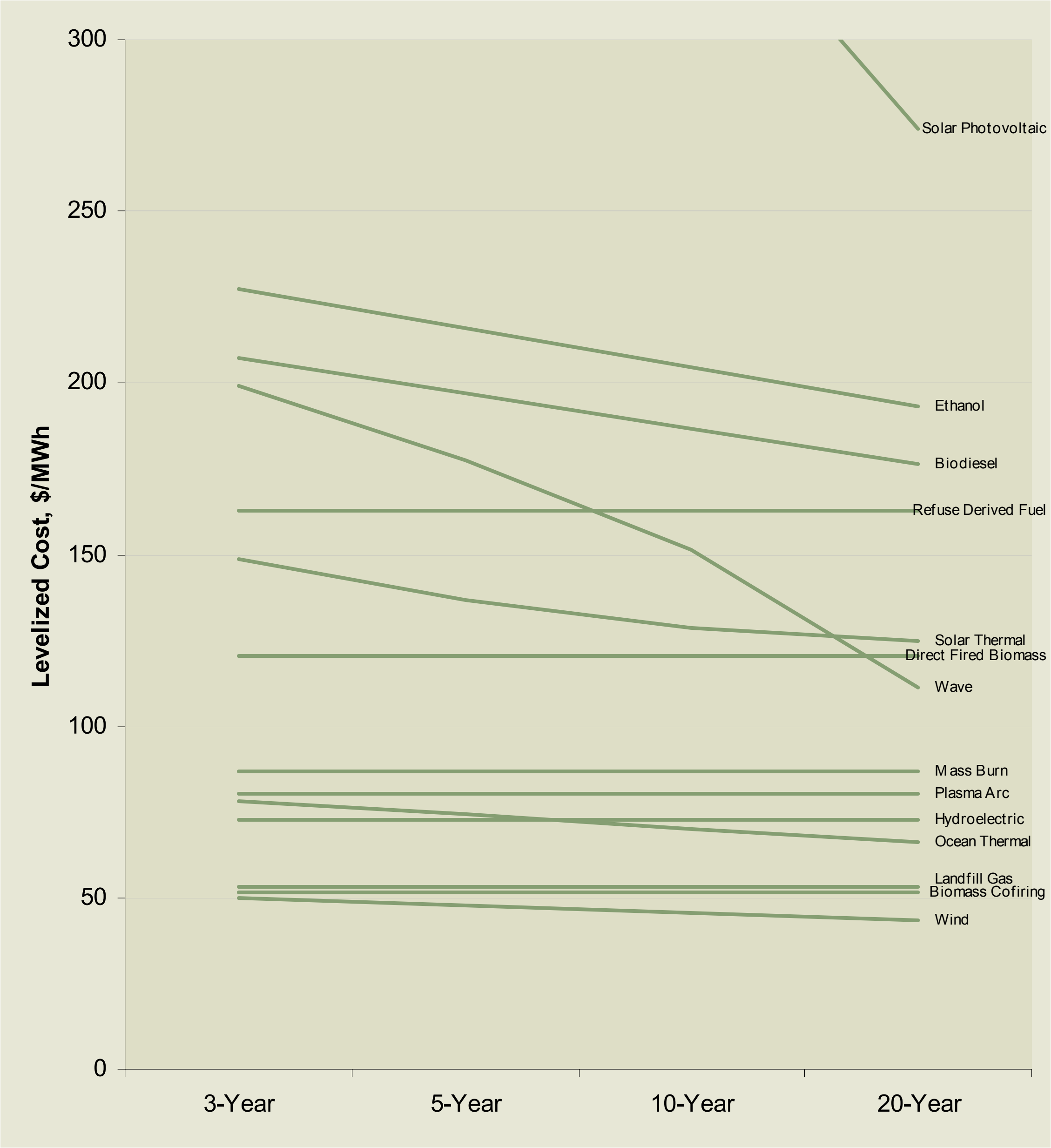

Figure 4-1. Trends in Average Levelized Cost of Energy for Renewable Resources (2005$).

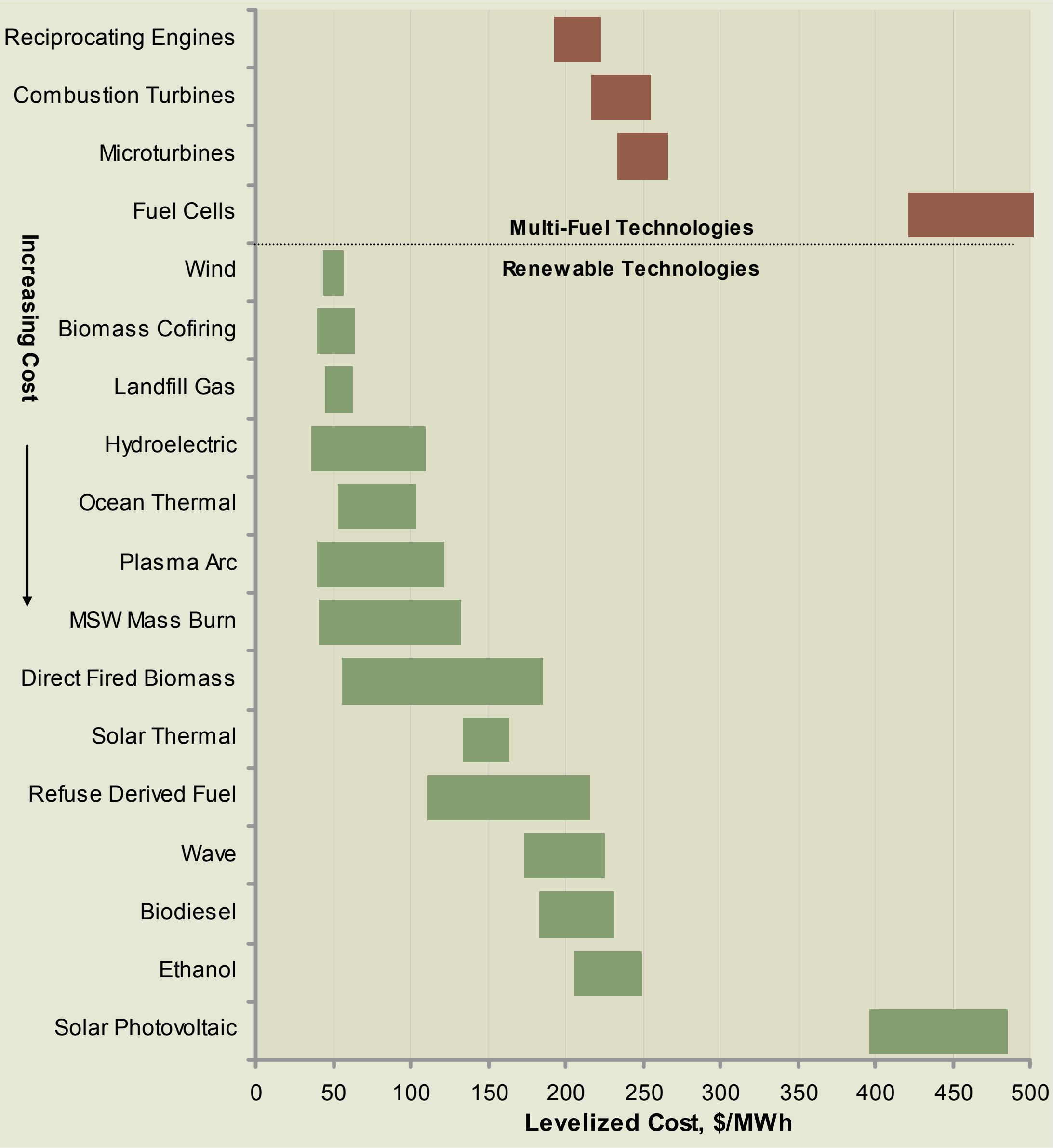

Figure 4-2. Range of Levelized Cost for Renewable Technologies (Three Year Timeframe).

Table 4-4. Cost of Energy Screening Results (Sorted by 3-Year Score).

Technology	3-Year	5-Year	10-Year	20-Year
Wind	100	100	100	100
Biomass Cofiring	99	99	99	99
Landfill Gas	98	98	98	98
Hydroelectric	89	89	89	89
Ocean Thermal	86	88	90	92
Plasma Arc	85	85	85	85
Mass Burn	82	82	82	82
Direct Fired Biomass	65	65	65	65
Solar Thermal	51	57	61	63
Refuse Derived Fuel	44	44	44	44
Wave	25	36	49	69
Biodiesel	21	27	32	37
Reciprocating Engines	21	21	21	21
Ethanol	11	17	23	28
Combustion Turbines	7	7	7	7
Microturbines	0	1	1	2
Solar Photovoltaic	0	0	0	0
Fuel Cells	0	0	0	0

4.4.2 Kauai Resource Potential

The developable potential was estimated for each renewable technology for the next 3, 5, 10 and 20 years. The background to these estimates is documented for each technology in the previous section under the "Kauai Outlook" subsections. The annual electricity generation (GWh/yr) estimates are shown in Figure 4-3.

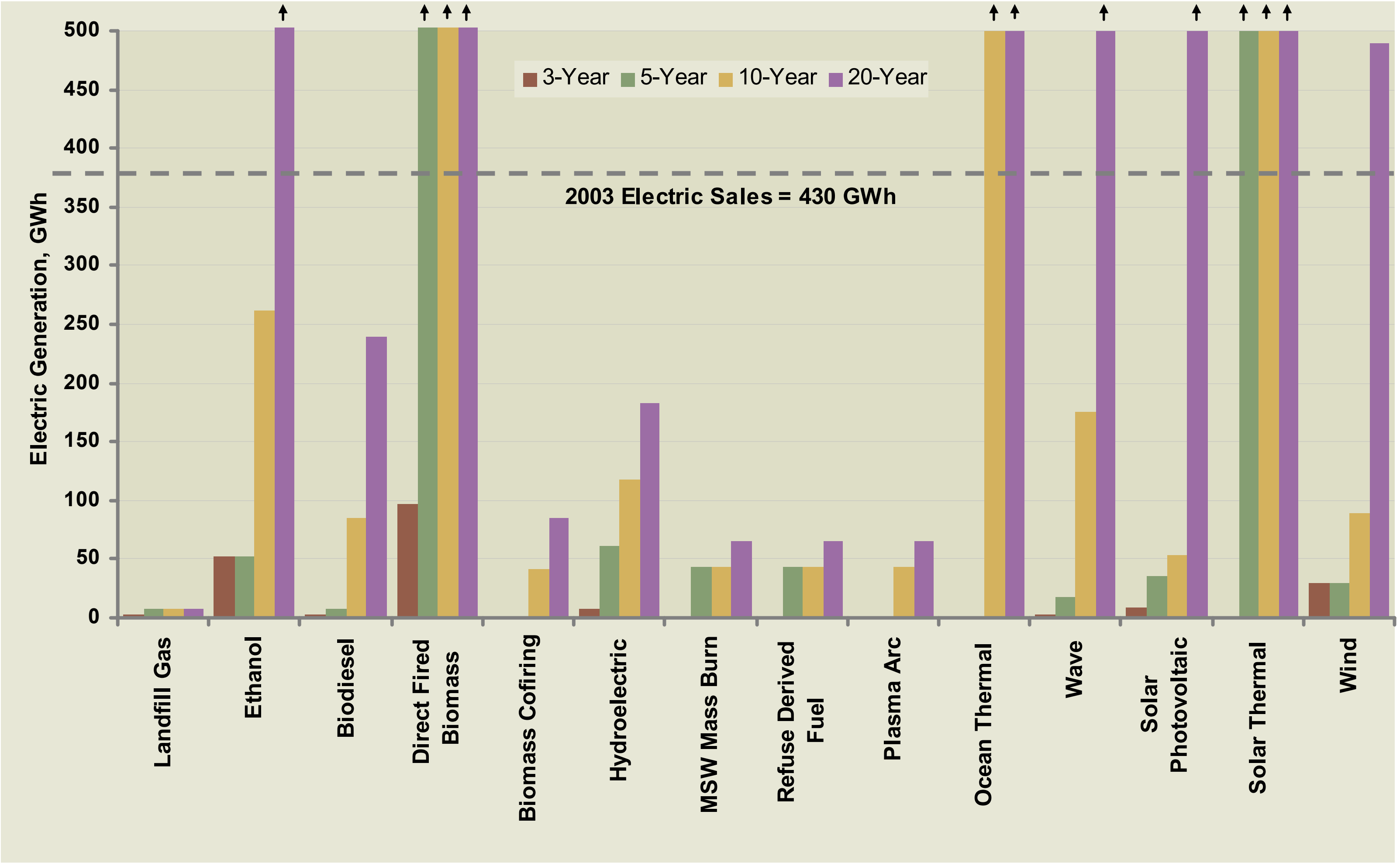

Figure 4-3. Developable Potential of Kauai Renewable Resources (Annual Generation, GWh/yr).

There are several resources that could theoretically meet all of Kauai's electricity needs (energy basis), which totaled about 430 GWh in 2003. However, in the near term (5 years) only direct fired biomass and solar thermal appear able to supply all Kauai's electrical needs. Most of the other technologies are limited by either (1) resource, (2) status of technology development (that is, the industry is not capable of supplying all the necessary equipment in such a short time), and (3) intermittency issues (that is, full scale implementation would require energy storage or other advanced solutions). In the long term, it appears that ethanol, ocean thermal, ocean wave, and solar photovoltaic should also each be able to supply enough electricity to meet the island's needs. Biodiesel, hydroelectric and wind also all have good developable potential. Biomass cofiring, landfill gas, and the waste to energy technologies all have relatively limited potential. Finally, geothermal, anaerobic digestion, and ocean tidal were all determined to have negligible developable resource potential and have been excluded from further analysis.

Resources able to supply in excess of 500 GWh per year were given a score of 100, while resources capable of supplying 5 GWh or less were given a score of 0; the others were scored proportionally in between these extremes. The results of the resource potential screening are provided in Table 4-5.

Table 4-5. Resource Potential Screening Results (Sorted by 3-Year Score).

Technology	3-Year	5-Year	10-Year	20-Year
Direct Fired Biomass	19	**100**	**100**	**100**
Ethanol	10	10	52	**100**
Wind	5	5	17	98
Solar Photovoltaic	1	6	10	**100**
Hydroelectric	1	11	23	36
Solar Thermal	0	**100**	**100**	**100**
Mass Burn	0	8	8	12
Refuse Derived Fuel	0	8	8	12
Wave	0	3	34	**100**
Biodiesel	0	0.4	16	47
Landfill Gas	0	0.4	0.4	0.4
Ocean Thermal	0	0	**100**	**100**
Plasma Arc	0	0	8	12
Biomass Cofiring	0	0	7	16

Notes:

* Negligible potential: geothermal, ocean tidal, anaerobic digestion.

** Multi-fuel generation technologies not shown (assumed 100 potential score).

Based on the 20-year resource potential estimates, calculations were made to demonstrate what percent of Kauai's annual energy demand could be met by the various resources. This is a theoretical calculation; it would not be advisable to rely on any single resource. Nevertheless, it again shows that there are several resources capable of supplying all of the island's energy needs. In addition, the theoretical barrels of No. 2 oil displaced has also been calculated as shown in Table 4-6.

Table 4-6. Resource Potential Comparisons.

Technology	20-Year Resource Potential GWh/yr	Theoretical Potential Percent of 2023 Electrical Energy Supply*	Barrels of Oil (No. 2) Displaced, bbl/yr**
Landfill Gas	7	2%	11,367
Ethanol	525	>100%	>740,000
Biodiesel	239	52%	388,118
Direct Fired Biomass	714	>100%	>740,000
Biomass Cofiring	84.1	18%	136,572
Hydroelectric	183	40%	297,178
Mass Burn	65.7	14%	106,692
Refuse Derived Fuel	65.7	14%	106,692
Plasma Arc	65.7	14%	106,692
Ocean Thermal	>500	>100%	>740,000
Wave	>500	>100%	>740,000
Solar Photovoltaic	>500	>100%	>740,000
Solar Thermal	>500	>100%	>740,000
Wind	490	>100%	>740,000

Notes:

* Assumes 2 percent load growth from 2003 value of 430 GWh/yr. 2023 value would be 456 GWh/yr.

** Based on 2023 electrical generation forecast and average thermal system heat rate of 9460 Btu/kWh.

4.4.3 Fit to KIUC Needs

The Fit to KIUC Needs criterion is a measure of the applicability and suitability of a technology to the KIUC system for each of the timeframes. This criterion encompasses the technology generation profile, scale of a typical project, and type of product (firm versus as-available). For this study it was assumed that firm and peaking capacity are the preferred generation products in the long-term (10 to 20 years), but that as-available resources (such as solar, wind, and hydro) are preferred in the 3 to 5-year timeframe. Alternative fuels (biodiesel and ethanol) were given the highest score, as these could be readily incorporated into the existing KIUC generation infrastructure as appropriate and cost effective. Ocean thermal energy conversion was given the lowest score in the near term because it is a capacity resource and plants would need to be very large to be economical. Table 4-7 shows the results of the evaluation.

Table 4-7. Fit to KIUC Needs Screening Results (Sorted by 3-Year Score).

Technology	3-Year	5-Year	10-Year	20-Year
Ethanol	100	100	100	100
Biodiesel	100	100	100	100
Solar Photovoltaic	85	85	85	85
Landfill Gas	75	75	100	100
Solar Thermal	75	75	75	75
Hydroelectric	75	75	50	50
Wave	75	75	50	50
Wind	75	75	50	50
Direct Fired Biomass	50	50	100	100
Mass Burn	50	50	100	100
Refuse Derived Fuel	50	50	100	100
Plasma Arc	50	50	100	100
Reciprocating Engines	50	50	100	100
Combustion Turbines	50	50	100	100
Microturbines	50	50	100	100
Fuel Cells	50	50	100	100
Biomass Cofiring	0	0	50	50
Ocean Thermal	0	0	25	25

4.4.4 Technology Maturity

The level of technology maturity is a measure of the relative development of a technology. In general, the less developed a specific technology, the higher the risk that a project will fail for technical, commercial, or other reasons. For example, a technology in research and development (e.g., plasma arc gasification) is much more likely to fail than a technology that is supported by several vendors and has been applied in numerous applications around the world (e.g., wind turbines).

The level of maturity of each technology was rated for the 3, 5, 10, and 20 year periods. Of the commercially available renewable energy technologies, hydroelectric power has the largest amount of installed capacity in the world today. It is followed by biomass direct combustion and then wind, geothermal, and solar energy. The following technologies are currently considered to be fully commercial and could make a contribution to the energy supply in Kauai in the near term (if sufficient resources are available):

- Anaerobic digestion
- Biomass Cofiring
- Landfill gas
- Biodiesel
- Direct fired biomass
- Hydroelectric
- Waste-to-energy mass burn

- Refuse derived fuel
- Solar photovoltaic
- Wind
- Geothermal
- Reciprocating engines
- Combustion turbines

Although advancements in these technologies will occur over the next 20 years, particularly solar photovoltaic technology, these technologies are fully capable of utility deployment in the near term.

The progression towards commercialization of the developmental technologies was estimated from Black & Veatch experience. Table 4-8 presents the expected development of technologies that are not yet fully commercial.

Table 4-8. Technology Maturity Screening Results.

Technology	3-Year	5-Year	10-Year	20-Year
Ethanol	50	75	**100**	**100**
Microturbines	50	75	**100**	**100**
Solar Thermal	50	50	75	**100**
Wave	25	50	75	**100**
Fuel Cells	25	50	75	**100**
Plasma Arc	25	25	50	75
Ocean Thermal	25	25	50	75

Ethanol production techniques have been successfully demonstrated and are currently being used around the world. However, experience with ethanol for power production is limited. With continued application over the next ten years, it is expected that power production from ethanol will be a fully commercial technology.

Plasma arc gasification has been demonstrated in several applications; however, there is still significant ongoing R&D into this technology. It is expected that within 10 years plasma arc gasification will be in the early commercial stages and will reach near fully commercial status within 20 years if additional facilities are built.

OTEC and WECS have been successfully demonstrated in several demonstration projects, however, there is still significant ongoing R&D activities. There are some plans for further demonstration of these technologies in Europe and Asia and it is expected that within 10 years the technology will be in the early commercial stages, and will reach near commercial status within 20 years if additional facilities are built.

Ocean tidal energy conversion has been successfully demonstrated and applied to large-scale commercial applications. However, there is still a limited number of operating facilities in the world, and there are no known major projects planned in the near future. Little additional development of the technology is planned.

Solar thermal energy technologies have been successfully demonstrated and there is currently over 350 MW of operating solar trough capacity in California. However, there have not been any plants built in the past 15 years. In the next 10 to 20 years solar thermal technologies could become fully commercial if additional facilities are built.

Microturbines are in the early stages of commercialization. The technology has been successfully demonstrated in applications with a wide variety of fuels including natural gas, landfill gas, digester gas, and other hydrocarbon fuels. With continued development and the emergence of a competitive vendor network, this technology is expected to reach fully commercial status in 10 years.

The four major fuel cell technologies are currently in the R&D and demonstration stages. Fuel cell vendors anticipate that early commercial products will be available within the next 5 years, and due to the high levels of government and private funding for fuel cell development, it is anticipated that full commercialization will be achieved within 20 years.

4.4.5 Environmental Impact

Renewable energy technologies were differentiated by their environmental impact relative to other renewable energy technologies, and the degree to which the technology contributed to sustainable use of natural resources in Kauai. A score of 50 is considered to be the baseline score for this criterion, with resources possessing additional positive or negative impacts receiving either higher or lower scores, respectively. Table 4-9 shows the results of the environmental impact screening.

Table 4-9. Environmental and Socioeconomic Impact Screening Results (Sorted by Combined Score).

Technology	Environmental	Socioeconomic
Ethanol	50	100
Biodiesel	50	100
Direct Fired Biomass	50	100
Plasma Arc	60	75
Solar Photovoltaic	85	50
Microturbines	75	60
Fuel Cells	75	60
Biomass Cofiring	50	75
Refuse Derived Fuel	50	75
Solar Thermal	75	50
Wind	75	50
Landfill Gas	50	50
Hydroelectric	50	50
Mass Burn	25	75
Ocean Thermal	25	75
Wave	50	50
Reciprocating Engines	50	50
Combustion Turbines	50	50

The majority of technologies received the baseline score of 50. These technologies, while relatively environmentally benign, do not possess outstanding environmental benefits or detriments to Kauai.

Mass burn, ocean thermal, and ocean tidal energy received lower scores because of potential adverse environmental impacts. There is concern about the potential for hazardous air emissions from MSW mass burn facilities. OTEC received a lower score because of outstanding questions about possible impacts to ocean life and ecosystems from possible changes to thermal, salinity, and nutrient gradients.

The plasma arc gasifier technology received a higher environmental impact score than the other waste to energy technologies because of superior solid waste disposal. Hazardous inorganic constituents in the waste are vitrified to form a glassy slag that is safer to dispose of than raw MSW or ash from traditional MSW mass burn facilities.

Solar photovoltaic received the highest environmental impact rating because there are minimal environmental impacts from solar photovoltaic generation and solar panels can be placed on existing structures (no new site development).

Solar thermal received a rating of 75 because there are no air emissions associated with this technology. However, development of a significant land area, and significant amounts of water for cooling would be required.

Wind received a score of 75 because while there are no air or wastewater emissions associated with this technology, there are potential impacts to avian populations and a significant amount of land is required for development of this resource.

Microturbines and fuel cells have the potential to produce lower emissions and operate at higher efficiencies than reciprocating engines or combustion turbines, thus these technologies received a better environmental impact score.

4.4.6 Socioeconomic Impact

Each renewable energy technology was evaluated based on the socioeconomic benefits enhancing the island's economy, health, and general well being from the development of the technology. Discriminating factors for this criterion included job creation, solving existing socioeconomic problems on the island, and transfer of knowledge to the island. Table 4-9 presents the results of the socioeconomic impact screening.

A score of 50 is considered to be the baseline for this category, with technologies that contribute additional benefits receiving a higher score. None of the technologies received a score lower than 50, because none of the technologies were deemed to produce negative socioeconomic impacts relative to conventional technologies.

Ethanol, biodiesel, and biomass production received scores of 100 because of the large benefits associated with the creation of a biomass fuel supply infrastructure which would generate a large number of jobs and capital investment in the local economy.

Waste to energy technologies including mass burn, refuse derived fuel, and plasma arc gasification, received socioeconomic impact scores of 75 due to the benefit of improved solid waste disposal with these technologies.

Microturbines and fuel cells received scores of 60 because the benefits associated with development of advanced technology on the island including knowledge transfer to local personnel and development of high tech jobs.

4.4.7 Incentives / Barriers

The degree of incentives or barriers to development is a measure of the difficulty of developing a particular resource. The existence of tax incentives, grant funding, or good public perception can aid in the development of a renewable resource. Conversely, a lack of incentives, or poor public perception, can prevent a project from being developed. The incentives or barriers to development of each technology were scored based on the criteria provided in Table 4-10.

Table 4-10. Incentives / Barriers Scoring Criteria.

Points	Incentives	Points	Barriers
2	Availability of credits, grants, subsidies, etc.	-1	Potential for negative public health impacts
2	Complementary to existing industry	-2	Not good fit with industry
3	Good public acceptance	-3	Negative public perception
2	Addresses waste disposal issues	-2	Visual impacts
2	Easily actionable	-2	Lack of supporting industry
1	Replicability / modularity	-2	Hurricane susceptible
2	Experienced O&M staff already on island	-3	Requires development of host facility

Each technology received positive and negative points for the incentives and barriers, respectively. The points from each category were then added together, multiplied by five and added to 50 to produce the final score. Table 4-11 provides the results of the Incentives / Barriers screening analysis.

Table 4-11. Incentives / Barriers Screening Results

	Incentives							Barriers							Score
	Credits, Subsidies, etc.	Complementary to Existing Industry	Goof Public Acceptance	Addresses Waste Disposal Issues	Easily Actionable	Replicability / Modularity	Experienced O&M Staff Already on Island	Possible Negative Public Health Impacts	Not Good Fit Existing Industry	Negative Public Perception	Possible Negative Visual Impacts	Lack of Supporting Industry	Hurricane Sensitive	Requires Development of Host Power Facility	
Points	2	2	3	2	2	1	2	-1	-2	-3	-2	-2	-2	-3	
Biodiesel	■	■	■		■	■									100
Solar Photovoltaic	■		■		■	■									90
Landfill Gas			■		■		■								85
Refuse Derived Fuel			■	■			■								85
Direct Fired Biomass	■	■	■				■			■					80
Fuel Cells	■	■	■			■						■			80
Anaerobic Digestion	■		■	■					■						75
Ethanol	■	■	■								■				75
Reciprocating Engines					■	■	■								75
Combustion Turbines					■	■	■								75
Microturbines			■		■	■						■			70
Plasma Arc			■	■								■			65
Solar Thermal	■		■									■			65
Geothermal	■		■									■			65
Hydroelectric						■	■			■					50
Wind	■		■			■					■	■	■		50
Biomass Cofiring		■					■			■				■	40
Mass Burn				■				■		■					40
Ocean Thermal										■	■		■		15
Ocean Tidal										■	■		■		15
Wave						■				■	■	■	■		10

This analysis concluded that landfill gas, biodiesel, direct fired biomass, refuse derived fuel, solar photovoltaics, and fuel cells have the greatest level of incentives and fewest barriers to development on Kauai. Although the incentives and barriers differed between these technologies, some similarities exist that produced high scores. All technologies are deemed to have good public acceptance, and credits or subsidies are generally available for all but landfill gas and refuse derived fuel. In addition, no significant barriers were identified to the development of any of these technologies.

Technologies with substantial barriers to development include all the ocean energy technologies, MSW mass burn, and biomass cofiring. The primary barrier to biomass cofiring is that it would require development of a new host coal facility.

Interestingly, wind and hydro received the same score: 50 out of 100. There is an even mix of both incentives and barriers to developing these types of projects.

4.4.8 Summary Conclusions

The scores for each of the criteria were summed together of 3, 5, 10 and 20 year timeframes. The results are shown in Table 4-12 for each of the periods. This information is also charted in Figure 4-4.

Table 4-12. Technology Screening Results (Sorted by Year 10).

Technology	3-Year	5-Year	10-Year	20-Year
Landfill Gas	*	78	81	81
Wind	80	80	79	87
Direct Biomass	65	73	78	78
Biomass Cofiring	*	*	77	78
Hydroelectric	72	73	72	73
Plasma Arc	*	*	72	74
MSW Mass Burn	*	66	71	72
Ocean Thermal	*	*	71	74
Solar Thermal	*	63	68	71
Refuse Derived Fuel	*	51	56	57
Biodiesel	47	50	54	59
Reciprocating Engine	47	47	52	52
Ethanol	37	42	52	59
Wave	*	39	49	68
Combustion Turbines	40	40	45	45
Microturbines	34	36	44	45
Fuel Cells	32	34	42	44
Solar Photovoltaic	33	34	34	43

* No developable potential in this timeframe.

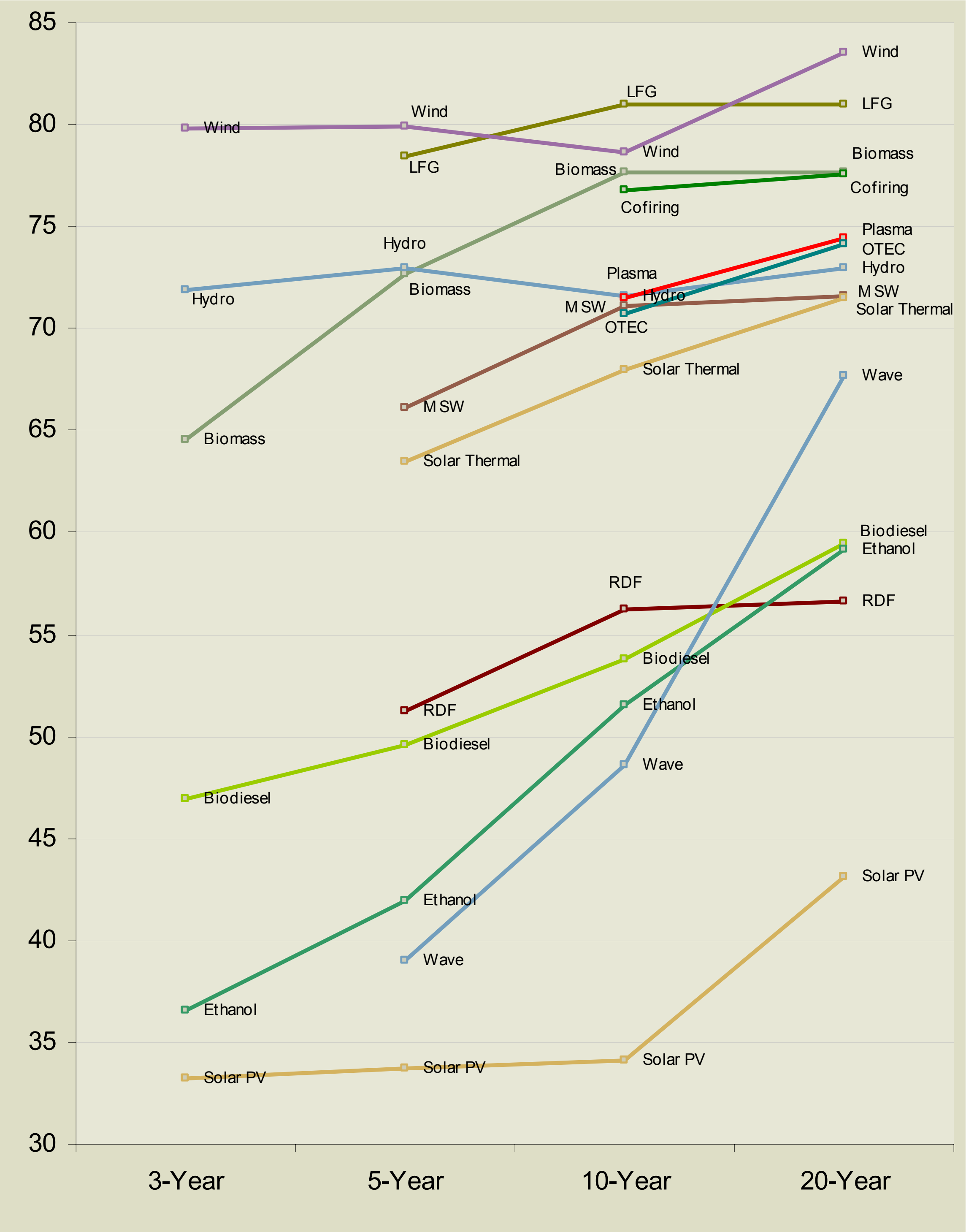

Figure 4-4. Change in Technology Screening Scores by Timeframe.

An example of the breakdown of the scores by criteria is shown for the ten-year timeframe in Figure 4-5.

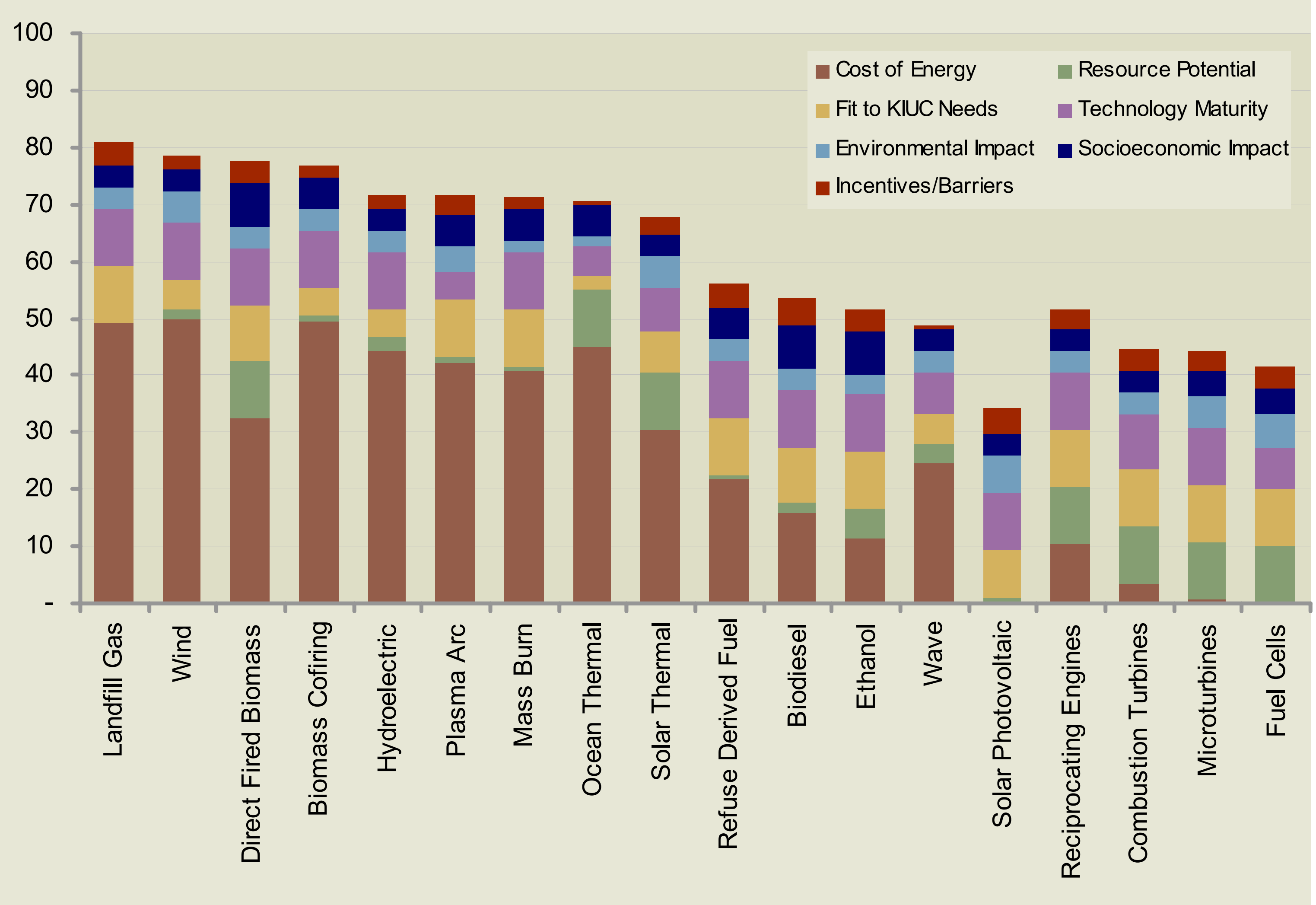

Figure 4-5. Screening Score Breakdown for 10-Year Timeframe.

In general, the scores trend upward over the 20 year evaluation period. The reasons for this are improvements in cost of electricity, developable resource, and technology maturity. Wave energy and biofuels are examples of technologies that start with relatively modest scores, but increase rapidly during the evaluation period. The small decline for wind and hydro between year 5 and year 10 is due to a change in the Fit to KIUC score that favors capacity resources in the long term.

Although cost of energy is by far the largest contributor to the overall score, a poor score in this category does not necessarily imply an overall low score. A good example is direct fired biomass, which makes up for its poor economics with high scores in resource potential, socioeconomic impacts, fit to KIUC needs, and technology maturity. On the other hand, biodiesel, ethanol, and solar photovoltaics are unable to overcome their poor economics with ancillary benefits.

Based on the results of the scoring process and the information detailed elsewhere in this report, the following observations are made about the technologies:

- **Landfill Gas** – Very good all around scores and low cost. However, potential is limited to around 1 MW.
- **Wind** – Very good all around with potentially lowest levelized cost of all technologies evaluated. Implementation of larger projects (>10 MW) will likely require advanced supporting technologies, such as energy storage.
- **Direct Fired Biomass / Biomass Cofiring** – High resource potential and socioeconomic impacts overcome relatively high cost of electricity. A project based on low cost resources (wood waste, bagasse, etc.) will have substantially improved economics. Cofiring of biomass in a new coal plant may also have attractive economics, *if* a coal plant can be built.
- **Hydroelectric** – The potential for hydroelectric is strong due to good resource potential and generally attractive economics. However, more than any other resource, hydro costs are highly site specific, and it is difficult to generalize about the competitiveness of the resource against the other renewables. Detailed information is needed on specific project opportunities to further assess the prospects for hydro on Kauai.
- **Waste to Energy** (Plasma Arc, MSW Mass Burn, and Refuse Derived Fuel) – Of the waste to energy options, MSW mass burn is likely the preferred option, even though plasma arc has a slightly higher score in the long term. The primary reason for this is that mass burn is proven technology, while plasma arc is still in early demonstration. The substantially higher cost of a refuse derived fuel plant does not appear to outweigh its slightly higher ancillary benefits. For all the waste to energy options, a tipping fee higher than the

$50/ton number used for this screening process will significantly enhance its score. A tipping fee of $65/ton or higher would give mass burn an overall score very near landfill gas and wind.

- **Ocean Thermal** – The relatively moderate projected cost of offshore ocean thermal makes it a potentially attractive resource in the 10 to 20 year timeframe. The projected cost assumes that the technology will develop through continued R&D, demonstration projects, and successful commercial installations. Given that Hawaii is one of the better locations in the world for ocean thermal, KIUC should monitor development of this technology.
- **Solar Thermal** – Similar to ocean thermal, solar thermal power could be an interesting option for KIUC – provided investments are made in the technology to allow continued cost and performance increases sufficient to match the projections presented here. Central station solar thermal is much more attractive economically than solar photovoltaics.
- **Biofuels** – Despite having high ancillary benefits (job creation, excellent fit to KIUC, and good incentives) ethanol and biodiesel appear unattractive due to high cost. The assumed fuel cost ($15-23/MBtu) may be competitive for transportation markets, but not for power production. That said, there is currently only a very limited market for alternative fuels in Hawaii, so it is difficult to estimate what the final fuel price will be for power production applications. Incentives and subsidies may significantly help biofuels. Further, KIUC could very easily integrate biodiesel into its existing fuel supply system without high capital costs or extensive equipment modifications.
- **Wave** – The prospects for wave energy are highly dependent on successful R&D, demonstration and commercialization of the technology. Kauai could be an ideal place for wave energy demonstration projects if incentives for demonstration project development are available. KIUC should monitor development of the technology for possible application in Kauai.
- **Solar photovoltaic** – Solar photovoltaics are the most expensive renewable energy technology. It is projected that solar photovoltaics will remain too expensive to be applied competitively at utility scale throughout the 20-year evaluation period. However, solar can be economical in niche applications (remote power supply, etc.) or when heavily subsidized. Finally, solar photovoltaics have extremely high public appeal, and despite their high cost, they are often a part of a utility's generating portfolio for this value alone.

- **Multi-fuel Generating Technologies** (Reciprocating Engines, Combustion Turbines, Microturbines, Fuel Cells) – Reciprocating engines and combustion turbines are fully commercial technologies offering competitive cost, reliable performance and good fuel flexibility. Microturbines and fuel cells do not currently offer the same cost / performance ratio, although it is projected that the gap will close over the next twenty years. The decision between engine generators and combustion turbines usually comes down to size. Combustion turbines are often preferred for applications greater than 5 MW, and engine generators for smaller sizes.

Black & Veatch recommends that landfill gas, wind, hydro, direct fired biomass, and MSW mass burn be examined for the rest of this report. The conclusions of the screening analysis are summarized in the table below.

Table 4-13. Renewable Technology Screening Summary Conclusions.
Attractive options, regardless of timeframe
Landfill gas
Wind
Hydro
Direct fired biomass / biomass cofiring
Waste to energy (MSW mass burn)
Reciprocating engines (< 5-10 MW)
Combustion turbines (> 5-10 MW)
Possibly attractive in mid to long term pending successful technology development
Ocean thermal
Solar thermal
Wave
Waste to energy (plasma)
Less cost effective options
Waste to energy (refuse derived fuel)
Biofuels
Solar photovoltaics
Microturbines
Fuel cells
Very limited or no potential
Geothermal
Anaerobic digestion (animal manure, sewage sludge)
Ocean tidal

5.0 Project Characterizations

Based on the recommendations of the previous section and discussion with KIUC, it was determined that the following technologies would be examined in the remainder of this report:

- Direct fired biomass
- Municipal solid waste mass burn
- Hydroelectric
- Wind
- Landfill Gas

5.1 Characterization Approach

Prototypical projects have been characterized for each technology class. For most technologies, this required a screening assessment of potential project options to determine optimum size, appropriate location, configuration, and other characteristics:

- **Biomass** – Project sizes from 5 to 30 MW were considered, and an optimum size was picked based on preliminary technical and economic analysis. The fuel mix changes based on the project size. Smaller projects can utilize lower cost waste biomass resources, while larger projects would need to rely on dedicated energy crops. The location for the biomass project has not been specified yet. A stoker boiler was selected as the basis for the project conceptual design due to its good mix of technical maturity, efficiency, and cost.
- **Municipal solid waste mass burn** – The previous sections compared various technology options for waste to energy, and it was determined that mass burn was the preferred conversion technology. The size of the MSW plant is limited to the available waste on the island. However, due to uncertainties in population, economic growth, and recycling trends, the amount of MSW available in the future is difficult to predict accurately. Therefore two project sizes, 200 and 300 tons per day, were compared, and the best size picked for additional analysis. As with biomass, the location for the MSW project has not been specified yet.
- **Combined biomass and MSW plant** – In addition to standalone biomass and MSW, a plant that combines both fuels was considered. Different equipment configurations were evaluated and a preferred approach and size characterized.

- **Hydroelectric** – Previous assessments identifying potential hydro projects on Kauai were reviewed and 49 possible project sites were cataloged. From this list, six promising projects were selected and characterized. The projects are located throughout the island and consist of new sites and upgrades of existing facilities.
- **Wind** – Eleven potential project areas were identified from the latest validated wind resource map for Kauai. These sites were screened for development potential. Two sites were identified as high potential, and five sites were identified as moderate potential. The other sites were dropped from consideration. Project size was limited to 7 MW based on direction from KIUC. Turbine sizes were restricted to less than 1 MW to ensure the machines could be erected and serviced with cranes available on the islands.
- **Landfill gas** – There is only one viable landfill gas project on Kauai, located at the Kekaha landfill. Black & Veatch estimated the energy production of this project after landfill closure in 2009. A project based on reciprocating engine technology could produce about 800 kW.

Due to their possible synergy, assessment of the biomass and MSW options is covered in a single section, 7.0 Biomass and Municipal Solid Waste. The other technologies are covered in the subsequent individual sections. Each technology section has the following subsections:

1. Basis for Assessment
2. Assessment of Contributing Resource
3. Project Option Screening
4. Technical Description
5. Power and Energy Production
   - 5.1 Plant Performance
   - 5.2 Operating Profile
6. Cost of Energy
   - 6.1 Capital Cost
   - 6.2 Operating and Maintenance Costs
   - 6.3 Incentives
   - 6.4 Life-cycle economics
7. Advantages and Disadvantages of Technology
   - 7.1 Fit to KIUC Needs
   - 7.2 Environmental Impact
   - 7.3 Socioeconomic Impact

7.4 Incentives / Barriers

8. Next Steps

5.2 General Assumptions

The following general assumptions were made in carrying out the project assessments. Financing assumptions are specified in the next section, and additional assumptions are documented in the respective technology sections.

- KIUC's will develop, own and operate all projects. Black & Veatch has also included economic analysis of private ownership to model the impacts of various financial incentives.
- Land purchase cost is $100,000 per acre.
- Insurance cost is 0.1 percent of the direct capital cost per year.
- Wind, landfill gas, and hydro projects have minimal permanent O&M staff (one person or less per project). Significant maintenance and repair work will be on a contract basis.
- Annual average fully burdened labor cost for plant O&M staff is $90,000 per year.
- There is sufficient available transmission capacity for projects. Other than transmission tie lines and project substations, no other T&D upgrade costs are included.
- Net power output estimates are for normal top load, adjusted for typical losses and degradation (that is, not "new and clean"). Transmission line losses are not included in the power output estimates.
- All cost estimates are in 2005 dollars and assume overnight construction.
- Levelized cost comparisons are done in 2009, the assumed on-line date of all projects.
- Hawaii general excise tax (4 percent) is included in cost estimates.
- Capital cost estimates are based on Black & Veatch experience with other projects, vendor quotes for major equipment items, and review of reference literature.
- Shipping is included in capital cost estimates.
- Construction labor rates and productivity have been adjusted for Hawaii conditions.
- Indirect project capital costs generally include (i) 10 percent for KIUC project management and administration and (ii) a project specific allowance for

project development and start-up expenses (feasibility studies, permitting, legal, engineering, construction management, spare parts, training, etc.).

5.3 Economic Modeling Approach

Based on the characteristics developed for each project, Black & Veatch calculated a levelized busbar generation cost ($/MWh). The levelized busbar cost is a method for comparison of the life-cycle costs of generating power from various projects on an equal economic basis. This cost considers the project performance, capital cost, fixed and variable operating costs, and fuel costs (if applicable). The levelized busbar cost can vary considerably based upon the financing and economic assumptions for a particular project. To capture the range of possible development scenarios for KIUC, the levelized cost of developing projects with KIUC financing and developer financing were considered. Under developer financing the power would be sold to KIUC under a power purchase agreement (PPA). Therefore, the levelized busbar cost represents the cost of a levelized price PPA. Developer financing offers the advantage of eligibility for tax-based federal renewable energy incentives, while KIUC funded projects offer the advantage of lower financing costs.

5.3.1 Economic Assumptions

The economic assumptions for the KIUC and developer financing scenarios are provided in Table 5-1 and Table 5-2, respectively. The assumptions are project specific and vary due to differing project life estimates. These assumptions supercede those in Table 2-1, which were used for the general technology screening.

Table 5-1. KIUC Financing Assumptions

	Hydro	Wind	LFG	Biomass	MSW
Debt to Equity Ratio	100 : 0	100 : 0	100 : 0	100 : 0	100 : 0
Cost of Debt, %	5.00%	5.00%	5.00%	5.00%	5.00%
Discount Rate, %	5.00%	5.00%	5.00%	5.00%	5.00%
Project Life, years	50	25	15	25	25
Debt Term, years	25	25	15	25	25
Fixed O&M Escalation, %	3.0%	3.0%	3.0%	3.0%	3.0%
Variable O&M Escalation, %	3.0%	3.0%	3.0%	3.0%	3.0%
Fuel Cost Escalation, %	3.0%	3.0%	3.0%	3.0%	3.0%
Levelized Fixed Charge Rate, %	5.12%	7.10%	9.63%	7.10%	7.10%
Capacity Credit	0%	0%	100%	100%	100%

5.3.2 Avoided Cost Assumptions

The avoided cost is the cost of installing and generating power from conventional sources that a utility avoids by installing renewable energy resources. The avoided cost includes both an avoided energy and capacity cost component.

Table 5-2. Developer Financing Assumptions

	Hydro	Wind	LFG	Biomass	MSW
Debt to Equity Ratio	60 : 40	60 : 40	60 : 40	60 : 40	60 : 40
Cost of Debt, %	8%	8%	8%	8%	8%
Cost of Equity, %	16%	16%	16%	16%	16%
Depreciation Life, years	20	5	5	7	7
Discount Rate, %	11.20%	11.20%	11.20%	11.20%	11.20%
Project Life, years	50	25	15	25	25
Debt Term, years	25	25	15	25	25
Fixed O&M Escalation, %	3.0%	3.0%	3.0%	3.0%	3.0%
Variable O&M Escalation, %	3.0%	3.0%	3.0%	3.0%	3.0%
Fuel Cost Escalation, %	3.0%	3.0%	3.0%	3.0%	3.0%
Tax Rate, %	35.00%	35.00%	35.00%	35.00%	35.00%
Production Tax Credit (PTC), $/MWh	9.00	18.00	9.00	9.00	9.00
PTC Term, years	5.00	10.00	5.00	5.00	5.00
PTC Escalation, %	2.50%	2.50%	2.50%	2.50%	2.50%
Levelized Fixed Charge Rate, %	12.58%	11.80%	14.23%	12.16%	12.16%
Capacity Credit	0%	0%	100%	100%	100%

The avoided energy cost is the cost of supplying each MWh of energy from an alternate source. In practice, this cost can be thought of as the cost of supplying energy from an alternative portfolio of generation resources (e.g., an alternative expansion plan). The avoided energy cost for this report was based on recent projections performed for KIUC by LCG Consulting.

The avoided capacity cost is the value to the electric system of a unit of capacity being available to serve load during peak conditions. Conceptually, the value of this capacity is equal to the capital carrying charge of the avoided generation resource (the next unit planned for addition to the system). As with the avoided energy value, the avoided capacity value was based on recent analysis by LCG Consulting.

Assumed avoided energy and capacity values are shown in Table 5-3. These values are based on the moderate load growth and fuel price case developed by LCG. It can be seen that for the next ten years, there is no value for capacity because KIUC already has sufficient capacity to meet needs. LCG Consulting only provided estimates through 2024, but most of the project lives will extend beyond this date. A 2 percent escalation was assumed for energy cost beyond 2024, and 2.4 percent escalation was assumed for capacity cost.

Table 5-3. Avoided Energy and Capacity Assumptions.

Year	Avoided Capacity Cost, $/kW	Avoided Energy Cost, $/MWh	Year	Avoided Capacity Cost, $/kW	Avoided Energy Cost, $/MWh
2009	0.00	111.89	2034	241.44	199.37
2010	0.00	121.46	2035	246.27	203.36
2011	0.00	131.10	2036	251.20	207.43
2012	0.00	133.40	2037	256.22	211.58
2013	0.00	139.93	2038	261.35	215.81
2014	160.34	146.48	2039	266.57	220.12
2015	162.00	155.09	2040	271.91	224.53
2016	160.15	159.54	2041	277.34	229.02
2017	192.08	155.25	2042	282.89	233.60
2018	192.80	164.57	2043	288.55	238.27
2019	192.35	168.47	2044	294.32	243.03
2020	183.14	166.80	2045	300.21	247.90
2021	203.74	163.22	2046	306.21	252.85
2022	200.11	168.86	2047	312.33	257.91
2023	196.32	159.73	2048	318.58	263.07
2024	214.88	164.41	2049	324.95	268.33
2025	202.03	166.83	2050	331.45	273.70
2026	206.07	170.16	2051	338.08	279.17
2027	210.19	173.57	2052	344.84	284.75
2028	214.40	177.04	2053	351.74	290.45
2029	218.68	180.58	2054	358.77	296.26
2030	223.06	184.19	2055	365.95	302.18
2031	227.52	187.87	2056	373.27	308.23
2032	232.07	191.63	2057	380.73	314.39
2033	236.71	195.46	2058	388.35	320.68

Not all renewable resources provide firm capacity. For example, wind and hydro are intermittent resources. To account for these variations, the avoided capacity value is modified by a capacity credit factor. The capacity credit is a measure of the percent of a project's capacity that contributes towards increasing the reliability of the electric system. For baseload, dispatchable renewable technologies such as biomass, MSW and landfill gas, the capacity credit is roughly equal to that for conventional fossil fueled plants. For intermittent renewable resources (wind and hydro), the capacity value is assumed to be zero for the purposes of this study. Although widespread implementation of these resources may be able to provide some probabilistic measure of firm capacity in larger interconnected grids, KIUC's small isolated grid has a greater need for generator reliability.

6.0 Renewable Energy Financial Incentives

A number of financial incentives are available for the installation of renewable energy and conversion technologies. These incentives can be of great significance because they often make the difference between a non-viable and a viable project, and can substantially influence profitability. Careful thought should be put into determining which incentives apply to each new project, and how to best take advantage of such incentives. The following discussion provides a list of existing and proposed programs that are available to new energy facilities.

It should be noted that the intent of this section is to provide general information on available incentives. Black & Veatch cannot provide tax advice concerning the implications of the specific incentive programs. Furthermore, although many of these incentives are designed as tax credits, it may still be possible for non-taxable entities, such as KIUC, to claim them by establishing facility ownership through a third-party taxable entity or other project structures.

This section describes the federal incentives available to renewable energy projects and other non-government programs designed to capture the value of renewable energy.

6.1 Federal Financial Incentives

The federal government began providing significant incentives for alternative energy during the oil embargo in the 1970s. The government has spent over $14 billion on research and development activities, in addition to tax and financial incentives for project development and energy production. The federal incentives reviewed for this project include the following

- Section 45 Tax Credit (Production Tax Credit)
- Reduced Depreciation Life
- Renewable Energy Production Incentive (REPI)
- Investment Tax Credit
- Farm Security and Rural Investment Act of 2002 Incentives
- Rural Economic Development Loan and Grant Program
- RUS Electric Loan Program
- High Energy Cost Grant Program
- Tribal Energy Program
- Miscellaneous Loan Guarantee and Grant Programs
- Federal Green Power Purchasing Goal

6.1.1 Production Tax Credit (Section 45)

The Section 45 tax credit (Production Tax Credit or PTC) is available to private entities subject to taxation for the production of electricity from various renewable energy technologies. The PTC formerly applied only to the production of electricity from wind, "closed-loop" biomass, and poultry waste, and had expired at the end of 2003. In October 2004, with the passing of the American Jobs Creation Act, the PTC was extended through December 31, 2005 and was expanded to include the following resources:

- "Open-loop" biomass
- Geothermal energy
- Solar energy
- Small irrigation hydropower
- Biomass cofiring
- Municipal solid waste (trash combustion and landfill gas)[46, 47]

Table 6-1 shows the provisions of the production tax credit, as revised by the American Jobs Creation Act.

Table 6-1. Production Tax Credit Provisions.

Resource	**Eligible In-service Dates**	**Credit Size***	**Term (years)**	**Transferable Credit?**	**Capacity Req.**
Wind	12/31/93 - 1/1/2006	Full	10	No	None
Biomass					
Closed-Loop	12/31/92 - 1/1/2006	Full	10	No	None
Closed-Loop Co-Firing	Before 1/1/2006	Full (% biomass heat input)	10	Yes**	None
Open-Loop	Before 1/1/2006	Half	5	Yes**	None
Livestock Waste	10/22/04 - 1/1/2006	Half	5	Yes**	>150 kW
Poultry Waste	12/31/99 - 1/1/2006	Full	10	No	None
Geothermal	10/22/04 - 1/1/2006	Full (can't also take ITC)	5	No	None
Solar	10/22/04 - 1/1/2006	Full (can't also take ITC)	5	No	None
Small Irrigation	10/22/04 - 1/1/2006	Half	5	No	150 kW – 5 MW
Landfill Gas	10/22/04 - 1/1/2006	Half (can't also take Sec. 29)	5	No	None

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[46] Database of State Incentives for Renewable Energy, "Renewable Electricity Production Tax Credit," available at www.dsireusa.org.

[47] House Ways and Means Committee, "American Jobs Creation Act of 2004," available at http://frwebgate.access.gpo.gov/cgi-bin/getdoc.cgi?dbname=108_cong_bills&docid=f:h4520enr.txt.pdf.

Municipal Solid Waste	10/22/04 - 1/1/2006	Half	5	No	None
Refined Coal	10/22/04 - 1/1/2009	$4.375/ton	10	No	None

Notes:
* All PTCs are inflation-adjusted and equaled $18/MWh ("Full") or $9/MWh ("Half") in 2004.
** The plant operator or lessee may receive the PTC.

Qualifying closed-loop biomass is defined as biomass grown exclusively for energy production. Open-loop biomass includes agricultural livestock waste, any solid, non-hazardous cellulosic waste (e.g., forestry residues, mill residues, tree trimmings, etc.), urban wood waste, and other agricultural wastes. Geothermal energy includes only production of electricity. Small irrigation hydropower refers to hydro generation facilities between 150 kW and 5 MW that generate power in an irrigation canal without the use of dams or impoundments. Municipal solid waste includes power generation with landfill gas and waste-to-energy (WTE) plants. Power generation facilities cofiring biomass with a fossil fuel, such as coal, are also included, provided that the biomass fuel meets the definition of closed-loop biomass.

The window of eligible in-service dates for the PTC varies by technology, but all technologies must currently be placed in service before January 1, 2006 (unless the incentive is extended at a later date). The credit is available for 10 years after the plant is placed in operation (or when the plant applies for the incentive, in the case of cofiring) for wind, closed-loop biomass, and facilities cofiring with closed-loop biomass. The credit is available for 5 years after the plant is placed in operation (or when the plant applies for the incentive, in the case of open-loop biomass) for open-loop biomass, geothermal, solar, small irrigation power, landfill gas, and WTE facilities.

Generally, to qualify for the PTC, a facility must be owned and operated by the taxpayer, and the electricity must be sold to an unrelated party. Not all corporate entities can utilize the tax credit, but for those that can, it serves to reduce their federal tax burden. The income tax credit amounts to 1.5 cents/kWh (subject to annual inflation adjustment and equal to 1.8 cents/kWh in 2004) of electricity generated by wind, solar, geothermal, and closed-loop biomass. The credit is equal to 0.75 cents/kWh (inflation adjusted, equal to 0.9 cents/kWh in 2004) for all other technologies. Any unused portion of the credit may be rolled back one year, or carried forward for 20 years.

The tax credit is proportionally reduced to zero if the national average contract price of electricity from a resource exceeds a "threshold price" of 8 to 11 cent/kWh (subject to annual inflation adjustment). To date, the price of electricity from eligible resources has remained well below the threshold price. However, only wind has taken advantage of the credit so far, and the impact of this provision on higher price resources, such as solar, could be substantial. The credit is also reduced by no more than half for construction-related grants, proceeds from tax-exempt bonds, subsidized energy financing, and any other credit allowable for property that is part of the project (collectively known as the Section 45 "anti-double-dipping provisions"). The general nature of this language means that the interaction of other federal and state incentives with the PTC is still somewhat unclear, though at least some indication of the IRS' thinking can be gleaned from reviewing private letter rulings issued to taxable entities seeking specific guidance related to the Section 45 credit.[48] For example, private letter ruling 200311021 implies that state production tax credits will not trigger the Section 45 anti-double-dipping provisions.[49] In general, incentives that provide up-front capital or construction-related support are more likely to trigger anti-double-dipping provisions than incentives that provide production-related support.

A new provision included with the expansion of the PTC allows parties other than the owner to receive the production tax credit for certain technologies. For closed-loop co-firing and open-loop biomass facilities, the plant operator, who is not necessarily the plant owner, may receive the PTC through a lease financing arrangement. For other technologies the owner of the project is the recipient of the PTC.

In the past, this credit has been extremely successful in encouraging development of wind energy but not biomass due to the very restrictive qualifications placed upon biomass before the most recent expansion of technology eligibility. In fact, no biomass plant has taken advantage of the credit to date. However, this will likely change with the expansion of the PTC, which now includes open-loop biomass facilities. A problem with the credit is the seemingly ever present threat of expiration, which promotes boom and bust building patterns. Various long-term extensions of the PTC were included with drafts of the 2003 Omnibus Energy Bill, but other controversial components of the bill prevented it from becoming law.

Implication for KIUC: This credit has historically been used to reduce the cost of wind generated electricity by 20-40 percent. The expansion of the credit is very significant, as it now includes all the technologies characterized in subsequent sections of this report. As a tax credit, the incentive has not been directly available to public entities, although alternative project structures could allow the value of the PTC to be captured. Although the credit is only available through 2005, it is expected that this will be extended.

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[48] Ryan Wiser, Mark Bolinger; Ernest Orlando Lawrence Berkeley National Laboratory, "Analyzing the Interaction Between State Tax Incentives and the Federal Production Tax Credit for Wind Power," September 2002.

[49] It is important to note that private letter rulings apply only to the taxable entity that requested the ruling, and should not be considered general tax guidance or precedent-setting.

6.1.2 Investment Tax Credit

The Investment Tax Credit is a 10 percent federal tax credit for purchases of solar and geothermal energy equipment. Only commercial entities can take this tax credit; there is no corresponding residential tax credit yet (the Bush administration has proposed a 15 percent solar tax credit for homes). Solar equipment eligible for the incentive includes solar electric and solar thermal systems. Up to 25 percent of the energy input to the system can be from non-solar sources (e.g., small gas turbines used to firm production), but this portion does not qualify for the credit.

If an investment in or purchase of solar property has been financed in part or in whole by subsidized energy financing or tax-exempt private activity bonds, then only the unsubsidized portion of the investment or purchase is eligible for the tax credit. For example, if $25,000 of a $50,000 purchase of solar property was financed by tax-exempt private activity bonds, then only a credit of $2,500 can be taken (10 percent of the $25,000 that was not subsidized). If financing for the entire $50,000 was subsidized, no tax credit can be taken. Further, the tax credit is limited to $25,000 per year, plus 25 percent of the total tax remaining after the credit is taken. The credit may be applied to the three preceding years and carried forward 15 years.[50]

As discussed previously, the production tax credit has been expanded to include geothermal and solar technologies. The language of the production tax credit extension does not allow claiming of both the PTC and the ITC. Project developers must choose one or the other. Further, the ITC also interacts with accelerated depreciation, as discussed further below.

Implication for KIUC: As with the other tax credits, the Investment Tax Credit is not directly applicable to KIUC. Additionally, for capital intensive solar projects, it is likely not advisable to surrender tax-exempt financing capability for the one-time 10 percent credit.

6.1.3 Accelerated Depreciation

Section 168 of the Internal Revenue Code contains a Modified Accelerated Cost Recovery System (MACRS) through which certain investments in biomass, solar, wind, and geothermal property can be recovered through accelerated depreciation deductions. There is no expiration date on the program. Under this program, certain power plant equipment may qualify for 5-year, 200 percent (i.e., double) declining-balance

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[50] US Department of Energy, "Financial Incentives for a Business to Invest in Renewable Energy Systems," available at http://www.eren.doe.gov/consumerinfo/refbriefs/la7.html, December 2000, accessed August 19, 2001.

depreciation, while other equipment may also receive (less) favorable depreciation treatment. Renewable energy property that will receive the 5-years MACRS includes:[51]

- Solar property that meets the same standards for eligibility required by the federal 10 percent investment tax credit.
- Wind property, including wind turbines, wind electric generators, storage devices, power conditioning equipment, transfer equipment, and related parts, up to the electrical transmission stage, subject to the same 25 percent limit on dual-fueled equipment required for solar property.
- Geothermal property including equipment used to produce, distribute, or use energy derived from a geothermal deposit, but only in the case of electricity generated by geothermal power, up to the electrical transmission stage.
- Biomass plants 80 MW or less that directly burn at least 50 percent biomass to generate electricity. Equipment that qualifies includes material handling, boilers, pollution controls, and other equipment involved in the production of electricity. If the facility is not considered a qualifying small power production facility, it can still qualify for 7-year, 200 percent declining-balance depreciation on certain equipment. The power plant must burn the biomass directly to qualify. Landfill gas and digester gas are not eligible under this definition.[52]

The accelerated depreciation law also specifies that the depreciable basis is reduced by the value of any cash incentives received by the project, and by half of any federal investment tax credits (e.g., the ITC). This provision has the effect of lowering the depreciable basis to 95 percent for projects that receive the ITC but no other cash incentives.

Implication for KIUC: Accelerated depreciation has a significant benefit for taxable entities, especially when combined with the Production Tax Credit above, but would not be applicable to KIUC unless working through a taxable entity.

6.1.4 Renewable Energy Production Incentive

The Renewable Energy Production Incentive (REPI) program was developed as a public sector counterpart to the PTC (Section 45) discussed previously. The program had

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[51] US Department of Energy, "Financial Incentives for a Business to Invest in Renewable Energy Systems," available at http://www.eren.doe.gov/consumerinfo/refbriefs/la7.html, December 2000, accessed August 19, 2001.

[52] Keith Martin, "Tax Issues and Incentives for Biomass Projects," available at: http://www.chadbourne.com/briefings/taxissues/Tax%20Issues%20and%20Incentives%20for%20Biomass%20Projects.htm, March 1995.

many of the same terms as the Section 45 tax credit, but was slightly less restrictive in its application (e.g., no anti-double-dipping provisions, greater number of renewable technologies eligible). Unfortunately, under-funding of the program offsets the increased scope. Additionally, the REPI authority expired on September 30, 2003, and no legislation has been passed to extend the program for new renewable generators.[53]

The REPI program was authorized under Section 1212 of the Energy Policy Act of 1992 to promote increased utilization of renewable energy sources. The program provided incentive payments for electricity produced and sold by new qualifying renewable energy generation facilities. To be eligible, generating facilities had to be owned by states, state political subdivisions, local government entities (such as municipal utilities), or not-for-profit electric cooperatives. The plant must have started operation between October 1, 1993 and September 30, 2003 to qualify for payments. Qualifying facilities must use solar, wind, geothermal, or biomass (except for municipal solid waste) generation technologies. Biomass sources were not restricted to "closed-loop" systems and the program included power generated from landfill gas.

Under the REPI program, qualifying facilities are eligible for an annual incentive payment of 1.5 cents/kWh (subject to annual inflation adjustment and equal to 1.8 cents/kWh in 2004). The payment is given for a period of ten years after the facility begins operation. The payment is subject to the availability of annual congressional appropriations. Because the amount allocated has been insufficient to cover all requests, payments have been based on a two tier structure. Tier 1 facilities receive priority treatment and consist of facilities that use solar, wind, geothermal, or closed-loop biomass. Tier 1 facilities receive either full payments or pro rata payments if funds are insufficient to cover full payments. The remaining funds, if any, are used to pay requests from Tier 2 facilities. Tier 2 consists of open-loop biomass technologies such as landfill gas, digester gas, and solid biomass burned to generate electricity. If funds are insufficient to make full payments to all Tier 2 facilities, payments are made on a pro rata basis. Any generation for which payment of the REPI is not made due to insufficient funds in a given year may be rolled forward and submitted for consideration in future years.

There are three major problems with the REPI program as it currently exists. First, the REPI program's reliance on annual Congressional appropriations limits its effectiveness as a financial incentive. Second, recent program appropriations have not been sufficient to make full incentive payments for electricity produced by all Tier 1 facilities, let alone Tier 2 facilities. Since 1996, funds have not been sufficient to make full payments to Tier 2 facilities. In fact, for the year 2002, payments of about $4.8

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[53] DOE Energy Efficiency and Renewable Energy; www.eere.energy.gov/wip/program/repi.html

million were made to Tier 1 and 2 facilities, while over $40 million (cumulative, from 2002 and prior years) due to Tier 2 facilities went unpaid (see Table 6-2). Finally, the credit is no longer available for new renewable energy generation facilities coming on-line after September 2003.

As a result, planners of renewable energy generation facilities have often not relied on REPI payments when evaluating the feasibility of projects. The DOE recognizes the problems of the REPI program and has sought and reviewed comments on options to make REPI a more effective incentive. These options would require either regulatory or statutory change and would need significantly higher levels of appropriations, which may be unrealistic. It does not appear that the program will be reinstated for new applications in the near future.

Table 6-2. REPI Program History.

Fiscal Year	Qualifying Facilities	Qualified Generation (MWh)	Total Payments	Cumulative Unpaid (Tier 2)
1998	19	528,899	$4,000,000	$9,747,420
1999	33	505,857	$1,500,000	$15,664,879
2000	33	684,941	$3,991,000	$24,755,332
2001	36	700,997	$3,787,000	$33,679,732
2002	44	734,115	$4,815,033	$40,211,074
2003	NA	NA	$3,714,920	NA

Source: DOE Energy Efficiency and Renewable Energy website http://www.eren.doe.gov/power/repi.html.

Implication for KIUC: KIUC would qualify for this program had the REPI program been extended. As it stands now this program will seemingly continue to underfund the projects enrolled in the program until it fully expires in 2013.

6.1.5 Farm Security and Rural Investment Act of 2002 Incentives

Among other provisions, the 2002 Farm Bill promotes the use of renewable energy on farms and rangeland through a number of different incentive mechanisms.[54] The following are the sections of the 2002 Farm Bill designed to support the development of renewable energy:

- **Conservation Reserve Program (CRP)** – the bill allows biomass and wind turbine installations to be sited on land enrolled in the CRP, subject to USDA

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[54] US Government Accountability Office, *Renewable Energy: Wind Power's Contribution to Electric Power Generation and Impact on Farms and Rural Communities*, September 2004

approval. Siting is contingent upon location, habitat, and purposes of the program. The installation of energy generation equipment does not reduce payments under the CRP.

- **Rural Development Title** – this program allows loans and loan guarantees to be made for renewable energy systems under the Consolidated Farm and Rural Development Act.
- **Business and Industry Direct Loan and Loan Guarantee Program** – the provision expands the program for rural development and allows farmer/rancher equity ownership in renewable energy projects. The limits per project range from $25 million to $40 million.
- **Value-Added Agricultural Product Market Development Grants** – this provision expands the definition of the term "value-added agricultural product" to include renewable energy. Consequently, grants up to $500,000 are now available to assist with feasibility studies, business plans, marketing strategies, and startup capital.
- **Energy Audit and Renewable Energy Development Program** – this section provides for competitive grants for organizations to conduct energy efficiency audits and renewable energy assessments for farmers, ranchers, and rural small businesses.
- **Renewable Energy Systems and Energy Efficiency Improvements** – this provision provides for loans, loan guarantees, and grants to farmers, ranchers, and rural small businesses to purchase and install renewable energy systems.

The primary programs by which the 2002 Farm Bill supports the development of new renewable energy projects are the Renewable Energy Systems and Energy Efficiency Improvements Program and the Value-Added Producer Grant Program.

The Farm Bill of 2002 authorized the Renewable Energy Systems and Energy Efficiency Improvements Program to provide loans, loan guarantees, and grants to agricultural producers and rural small businesses to purchase renewable energy systems and make energy efficiency improvements.[55] Due to time and staffing constraints, the USDA has only offered grants in 2003 and 2004. Public proceedings are ongoing to develop final rules for the issuance of loans and loan guarantees. The program is slated to end in 2007, with a total funding limit of $115 million. In 2003 a total of about $21 million in grants were made, with $60,996 in grant funds going to projects in Hawaii. In 2004 a total of $22.8 million in grants were issued, but no grant recipients were located in

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[55] Database of State Incentives for Renewable Energy, *Renewable Energy Systems and Energy Efficiency Improvements Program*, available at www.dsireusa.org

Hawaii. Final rules on the loan and loan guarantee portions of this program are expected at the end of 2004 or beginning of 2005. At this time, it is unclear what the distribution of grants, loans, and loan guarantees will be in 2005.

The Farm Bill of 2002 also included renewable energy in the definition of value-added farm products. This change makes renewable energy projects eligible for up to $500,000 in grant funding through the Value-Added Producer Grant (VAPG) program.[56] The program is available for agricultural producers, farmer or rancher cooperatives, agricultural producer groups, and majority-controlled, producer-based business ventures. The grants apply to planning activities and working capital for marketing value added products based on photovoltaics, wind, biomass, hydroelectric, hydrogen, manure digestion, ethanol, and biodiesel technologies and processes. Grants under this program have been administered since 2001, and $13.2 million was made available for Fiscal Year 2004, with about $135,000 going to Hawaiian firms. At this time it is not clear what the level of funding for the program will be in 2005.

Implication for KIUC: Under one of these programs it may be possible for KIUC to receive grant funding or low-interest loans for development of renewable energy projects. Further, local agribusinesses could utilize the program to develop renewable energy projects to sell power to KIUC more cost effectively. The amount of funding received would be dependent upon the proposed project.

6.1.6 Rural Economic Development Loan and Grant Program

The USDA administers the Rural Economic Development Loan and Grant (REDL&G) program with the goal of spurring rural economic development through government backed loans and grants to rural electric and telephone utilities.[57] Since the program's inception in 1989, loans and grants have been administered to over 1,000 projects for a total of over $250 million. Types of projects funded include improvements to local businesses, health care facilities, water systems, and renewable energy projects. The source of funding for the REDL&G program is the interest earning differential on the RUS Cushion of Credit Account, which began to decline in the latter part of the 1990's. Subsequently, the National Rural Electric Cooperative Association (NRECA) lobbied for a new source of funding to restore this valuable program. A new source of funding was provided through the 2002 Farm Bill and the program should begin to offer more zero

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[56] Database of State Incentives for Renewable Energy, *Value-Added Producer Grant Program*, available at www.dsireusa.org

[57] Bob McLaury, *USDA's REDL&G Program: What Its Accomplished. An Even Brighter Future. A Tool to Make it Easier*, Presented at the CFC Forum 2003, available at http://www.nrucfc.com/conferences/Forum2003/ppt/McLaury-Economic_Dev.ppt#1

interest loans and grants for rural development projects, including renewable energy projects in 2005.[58]

Implication for KIUC: This program would indirectly benefit KIUC. This program could be used to obtain inexpensive financing for a customer owned renewable energy projects on the island, but it is too small to directly fund a large-scale KIUC project.

6.1.7 RUS Electric Loan Program

Through direct loans and loan guarantees, the USDA Rural Utilities Service (RUS) provides capital for the construction and maintenance of rural electric generation, transmission, and distribution infrastructure.[59] States, territories, municipalities, cooperatives, and other organizations that provide retail electric service to rural areas are eligible for the program. Investments in renewable energy generating equipment are covered by the Treasury Rate Loan program, which provides loans at the US Treasury interest rate. These loans are available to both retail and wholesale generation providers, and are available for a term of up to 35 years. Normally, this interest rate would not be available to public or private borrowers with even the best credit rating. There is no expected termination date of this program in the foreseeable future.

Implication for KIUC: The RUS Electric Loan Program could provide KIUC with low-cost financing for the addition of renewable generation assets. The low-interest loans would inevitably improve the economics of any of the proposed projects for this study.

6.1.8 High Energy Cost Grant Program

The High Energy Cost Grant Program is administered by the Rural Electric Service of the USDA. This program is designed to help mitigate high home energy costs, in excess of 275 percent of the national average, through financial assistance.[60] The program has the authority to fund improvements to generation, transmission, and distribution system improvements; however, recent funding has included on- and off-grid renewable energy systems and implementation of demand-side management and energy conservation programs. States, political subdivisions of states, and agencies organized under state law are eligible to receive funds under this program. In 2003, $14.9 million in grants were distributed to projects in seven states. In 2004, $11.3 million in funding was authorized for funding of six projects. A number of conventional and renewable energy projects have been funded in Alaska and on Indian Reservations where the cost of

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[58] George Stuteville, *NRECA, White House Agree on REDL&G*, Published in Electric Co-op Today, October 29, 2004.

[59] Information of the RUS Electric Program available at http://www.usda.gov/rus/electric/index.htm

[60] USDA High Energy Cost Grant Program information available at http://www.usda.gov/rus/electric/hecgp/

energy is often prohibitively high for the relatively low income levels of the populations in these communities. Some projects have also been funded on Hawaii. In 2003, Maui Electric Company received a grant which enabled the sale of solar water heaters. The funding level and proposal requirements for 2005 are expected to be similar to that in 2004.

Implication for KIUC: This program is applicable to KIUC with residential rates at nearly triple the national average. This program could be an excellent opportunity for KIUC to receive funding for new generation resources.

6.1.9 Tribal Energy Program

The purpose of the DOE Tribal Energy Program is to promote tribal energy self-sufficiency, economic development, and employment on tribal lands through the use of renewable energy and energy efficiency technologies.[61] The program provides funding assistance for the full range of project development including strategic planning, energy options analysis, capacity building, feasibility studies, educational programs, and project construction. The funding mechanism of the program is through grants to the tribal governments for each of the pre-development and development opportunities. Over the past two years 45 projects have been funded across the US for a total of $8.4 million. Projects included feasibility studies, project implementation, and other pre-development efforts. There is no current indication of what the funding level will be for 2005 and beyond, but will likely be similar to that in recent history.

Implication for KIUC: Proceeds from this program would likely not directly benefit KIUC. Projects could be cooperatively pursued with other eligible parties. Currently the program does not apply to Hawaiian Home Lands. However, it may be possible to approach DOE with a compelling project concept and still receive funding.[62]

6.1.10 Miscellaneous Loan Guarantee and Grant Programs

From time to time various federal agencies such as the DOE, USDA, Environmental Protection Agency, Forest Service and others offer loans, loan guarantees, and grants for the development of renewable energy projects. These loans and grants are often targeted at specific technology development or policy objectives, which tend to change over time. For example, in recent years the USFS has issued grants for projects to selectively thin forests as a forest fire prevention measure. These types of grants generally follow large forest fire seasons which raise the public consciousness of forest

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[61] US Department of Energy, *Renewable Energy Development on Tribal Lands*, available at www.nrel.gov/docs/fy04osti/35509.pdf

[62] Personal conversation with Roger Taylor, National Renewable Energy Laboratory, Denver, CO, November 10, 2004.

fire prevention. Grant programs are generally advertised with a Notice of Funds Available (NOFA) in the *Federal Register*. At this time it is not possible to forecast exactly which technologies or project types will be supported by federal agencies, and for whom these grants will be applicable.

6.1.11 Federal Green Power Purchasing Goal

The US government is the single largest consumer of energy. With the goal of improving the US government's energy management, Executive Order 13123 was promulgated by President Clinton, which requires federal agencies to increase purchases of renewable energy to a percentage set by the Secretary of Energy.[63] In 2000, Secretary of Energy Bill Richardson set the target for federal agencies at 2.5 percent of electricity consumption by 2005, and 20,000 solar roofs on government facilities by 2010.[64] Since the enactment of this goal, various federal agencies have been active in installing renewable energy projects and purchasing renewable energy to meet this goal. Consequently, government renewable energy use has increased to about 1.25 percent, or about 48 percent of the goal for 2005.

Implication for KIUC: This goal may create opportunities for KIUC to work with the local military or other government facilities. Joint projects could be developed, or KIUC could negotiate with the government to be an "anchor tenant" for a new green pricing program.

6.2 Valuing Renewable Energy Attributes

In addition to the government incentive programs described previously, utilities, marketers, and others have developed additional programs to address the sometimes higher cost of renewable energy. This section describes green pricing, green marketing, and tradable renewable energy credits.

6.2.1 Green Pricing

A small but significant percentage of the population is willing to pay extra for electricity generated from "green" or renewable resources. Green pricing of electricity is offered to utility customers in regulated markets. Customers can choose to pay a small premium on their monthly electricity bills to cover the higher cost of renewable energy. Typical premiums for green pricing are 1¢/kWh to 4¢/kWh, but can be much higher for specialty products, such as solar power.

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[63] Database of State Incentives for Renewable Energy, *Federal Government – Green Power Purchasing Goal*, Available at www.dsireusa.org

[64] President Clinton, *Executive Order 13123 – Greening the Government through Effective Energy Management*, Printed in the *Federal Registry* on Tuesday June 8, 1999.

There are numerous green pricing mechanisms, and almost all are voluntary for the consumer. Consumers can commit to receiving a portion of the bill from renewable sources, paying a set premium per kWh. Participants can purchase blocks of generation (such as 100 kWh) for a monthly price. Some programs are based on voluntary contributions sent in each month at the discretion of ratepayers. Some programs require time commitments from consumers, such as a minimum of one year of purchases.

Contributions can be used for many purposes. Utilities can own renewable projects, purchase renewable power from a third party, purchase renewable energy credits (discussed later), or place the money in a fund to support feasibility, education, and research programs. There are also companies that will provide all the program marketing and energy on a "turnkey" basis. Power for green pricing programs can come from a wide range of renewable sources, and can be from new or existing projects. Limits on the use of funds may be regulated by local state commissions, but there are no national standards enforced.

There is a general disparity between the percent of customers who say they are willing to pay more for green power and those that actually do. Nationally, the average participation rate in utility green pricing programs is only 1.2 percent, with a range for top performers of 4 to 11 percent.[65] A list of the utility top green pricing programs, in term of participants, is included in Table 6-3.

More than 500 utilities offer green pricing programs. According to the Department of Energy Green Power Network, green pricing programs have so far supported the development of over 500 MW of renewable energy, predominately wind and biomass.[66]

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[65] Lori Bird, NREL, "Trends in Utility Green Pricing Programs," presented at the 9th National Green Power Marketing Conference, October 2004.

[66] US Department of Energy, "Estimates of New Renewable Energy Capacity Serving U.S. Green Power Markets (2003)," available at: http://www.eere.energy.gov/greenpower/resources/tables/new_gp_cap.shtml, accessed February 2005.

Table 6-3. Top Utility Green Pricing Programs by Customer Participation.

Rank	Utility	Program Name(s)	Participants
1	Xcel Energy	Windsource, Renewable Energy Trust	43,039
2	Los Angeles Department of Water and Power	Green Power for a Green L.A.	29,677
3	Portland General Electric Company*	Clean Wind, Renewable Usage, Healthy Habitat	26,893
4	Sacramento Municipal Utility District	Greenergy, PV Pioneers I	24,542
5	PacifiCorp*	Blue Sky, Renewable Usage, Habitat Option	23,351
6	We Energies	Energy for Tomorrow	10,760
7	Alliant Energy	Second Nature	9,519
8	Austin Energy	GreenChoice	7,462
9	Tennessee Valley Authority	Green Power Switch	7,364
10	Wisconsin Public Service	SolarWise for Schools, NatureWise	6,157

Source: Energy Efficiency and Renewable Energy Network, February 2005
Note:
* Marketed in partnership with Green Mountain Energy Company.

Implication for KIUC: A green pricing program may be a good method for KIUC to test local desire for renewable energy projects. By implementing such a program, those customers who support renewable energy may do so directly through their monthly electric bill. This reduces rate impacts to other customers, while satisfying the wishes of those who want more renewable energy in the KIUC energy mix.

6.2.2 Green Marketing

Green power marketing is the sale of renewable energy in competitive markets. When a state deregulates its electric market, the consumer can choose an energy provider, and they consequently have the option to choose a green energy provider. Green power is somewhat analogous to other premium products, such as bottled water, and is one of the few ways that power producers can claim to have a differentiated, brand name product. Green marketers are under constant pressure to minimize the premiums they charge while still covering the costs associated with consumer education and the actual marketing of their product. Average premiums charged for green energy vary from around 1¢/kWh to 2¢/kWh. Currently, at least ten states have green energy marketed as a competitive energy choice, including Texas and Pennsylvania. Perhaps the most recognizable green marketer is Green Mountain.

Implication for KIUC: Because the electric power sector is not deregulated in Hawaii, green marketing programs are not applicable to KIUC.

6.2.3 Renewable Energy Credits

As more states (such as Hawaii) and perhaps even the federal government set mandates for renewable generation, markets have arisen to allow local and national trading of renewable power. This power is typically a premium product, traded at higher prices than conventionally generated electricity. Renewable Energy Credits (RECs) can capture the value of this credit and increase revenue opportunities for renewable energy generators.

When a mandate is set for a portion of a utility's generation to come from renewable sources, the utility has two general options: to build a renewable energy plant or to buy power from another company. The purchase of RECs allows a different way to buy the renewable characteristics of a generation source without necessarily purchasing the associated energy. This is accomplished by "unbundling" the environmental benefit from the electricity. The unbundled environmental benefit is known as a REC. RECs are conceptually similar to air pollution credits (e.g. NO_x credits).

When a renewable generating source is serving as a stand-alone generator, they will sell their power at some market or contracted price. If their current agreement(s) does not specifically include the green aspect of their generation, then the owner may wish to also sell the green attributes of their energy as a REC. The unbundling of the electricity from the green characteristics allows another entity to purchase the green component of the energy (REC) without having to buy the associated electricity.

It is common for questions to arise about the verification of the renewable generation to be purchased. Buyers want to be assured that they are only purchasing power generated from genuine "green" sources. They also want to know that the sale includes only RECs equivalent to actual kWh produced. Some states, such as Texas, have already created their own certification programs to ensure the "quality" of the generation and to avoid generators from selling their RECs more than once (known as double counting). Other organizations, such as Green-e, have also started that offer third-party certification services for renewable power.

Trading of RECs is still relatively immature, although increasing rapidly. Currently, RECs are either used to satisfy voluntary green pricing / marketing programs or used for compliance with state renewable mandates. The voluntary REC market is thinly traded around the country. REC values vary depending on the type of resource;

solar and wind resources have the highest REC values (up to 20 ¢/kWh for solar), while biomass, geothermal, and hydro are much lower.

Texas, Massachusetts, Connecticut and New Jersey all have REC trading markets used to help meet state mandates for renewable energy. In New England, where demand is higher than the current renewable energy supply, REC values are as high as 5 ¢/kWh, which is as much as the base energy value. In Texas, the values are more modest, around 1.5 ¢/kWh.

Implication for KIUC: The newly modified renewable portfolio standard for Hawaii creates the potential for KIUC to benefit from renewable energy credits. The isolation of the Hawaiian islands combined with varying population and renewable resource distributions among the islands, makes trading of renewable energy credits a sensible method to comply with the requirements of the RPS. On the one hand, KIUC could purchase excess RECs from other island utilities. This would limit capital expenditures on new renewable energy plants – plants which may not be needed in the near term to meet the island's electrical needs. On the other hand, Kauai has ample renewable resource potential. If new projects were developed, the excess RECs could be sold to other utilities for additional revenue.

6.3 Summary

Federal and state governments have developed a number of policy approaches to support renewable energy development. Table 6-4 summarizes the various incentive programs evaluated in this study. The most prevalent and successful policies have been tax incentives, particularly the federal PTC, and to a lesser extent the ITC and accelerated depreciation. The well-intentioned REPI program had limited success in spurring development because of inconsistent funding. Tax-exempt entities are currently limited to grant and loan programs, of which few exist at present. Moreover, federally-funded grant and loan programs have typically been intended to support small-scale demonstration projects rather than utility-scale deployment. Public utilities therefore draw the greatest benefit from their tax-exempt status and the ability to utilize low cost debt. KIUC may also wish to further investigate the benefits of green pricing programs and renewable energy credits.

Table 6-4. Renewable Energy Incentives Summary.

Incentive	Description	Recommendation
Federal Incentives		
Production Tax Credit	1.8 cent/kWh (inflation adjusted) for wind, solar, geothermal, and closed loop biomass electricity. 0.9 cent/kWh credit for open-loop biomass, small irrigation power, and municipal solid waste. Wind and closed-loop biomass receive PTC for 10-years, other technologies receive credit for five years. Taxable entity needs to be part of project structure to claim credit.	Consider power purchase from a taxable third-party developer who can claim the PTC. Investigate alternative project structures to may leverage the PTC and KIUC low interest financing.
Investment Tax Credit	10 percent investment tax credit for new solar and geothermal projects	Not applicable under tax-exempt financing.
Reduced Depreciation Life	5-year accelerated depreciation on alternative energy projects. Requires ownership by taxable entity.	Utilize if taxable entity is involved in project.
Renewable Energy Production Incentive	10-year 1.8 cent/kWh (inflation adjusted) for wind, biomass, geothermal, and solar. This a public entity alternative to the PTC. Subject to annual congressional appropriations and substantially underfunded.	Monitor the status of this program and apply for funding should the program be extended in the future.
2002 Farm Bill	Value-Added Agricultural Product Market Development Grants, and Renewable Energy and Energy Efficiency Improvements programs provide grant, loan, and loan guarantee for development of renewable energy and energy efficiency projects.	Consider applying for development grants for project development and construction expenses.
REDL&G	Program to provide grants, loans, and loan guarantees to agricultural producers and rural small businesses for development of renewable energy projects.	Publicize REDL&G program to coop members.
RUS Loans	The USDA RUS offers low interest loans to rural utilities at US Treasury rates normally not available to public or private borrowers.	Consider applying for RUS financing for renewable energy projects.
High Energy Cost Program	Provides grants for renewable and energy conservation projects to help mitigate high energy costs.	Consider applying for grant funding for development/construction of renewable energy projects.
Tribal Energy Program	Provides grant funding for renewable energy and conservation project pre-development and development activities on Indian Reservations.	Publicize program to the Department of Hawaiian Home Lands and work with the department to investigate grant funding if feasible.

Table 6-4. Renewable Energy Incentives Summary.

Incentive	Description	Recommendation
Misc. Loan & Grant Programs	Miscellaneous grants for development of renewable energy projects.	Monitor for potential grant opportunities.
Green Power Purchasing Goal	Goal for federal government facilities to purchase 2.5 percent of electricity from renewable sources by 2005, and 20,000 solar roofs by 2010.	Contact military base and government facilities managers regarding joint development or purchase of renewable energy.
Non-Government Incentives		
Green Pricing	Voluntary program where utility customers pay premium for renewable electricity. Regulated markets.	Consider developing program to test customer demand.
Green Marketing	Voluntary program where electricity customers pay premium for renewable electricity. Deregulated markets.	Not applicable to Hawaii.
Renewable Energy Credits	Tradable credits representing the renewable attributes of electricity – separate from the actual energy. May be used to satisfy voluntary programs or renewable portfolio standard requirements.	Evaluate as a flexible mechanism to meet RPS requirements, or sell excess credits to other Hawaii utilities.

7.0 Biomass and Municipal Solid Waste

Biomass and waste-to-energy (WTE) power plants use substantially similar technologies. In the case of Kauai, it is possible that the best economies of scale for a solid fuel combustion project will occur by combining the two fuels in a common project. This is not typical in most locations, but constrained fuel resources make this a reasonable option to consider. This section, therefore, will combine the two fuels and technologies with alternately separate and combined discussion of plant configurations, as appropriate.

7.1 Basis for Assessment

The Interim Report identified typical biomass and WTE generation technologies. The understanding and basis for these characterizations come from Black & Veatch's extensive history of designing and constructing these plants.

This section presents multiple options for biomass or WTE plants. Determining which best suits KIUC's needs is a matter of understanding plant performance and cost, economies of scale, fuel supply, and operation and maintenance requirements. These issues can be resolved into the following questions:

- On a busbar cost basis, is it better to build a small plant burning low cost residue; or a larger, more efficient plant burning more expensive fuel?
- What are the options for combining biomass and WTE fuels in terms of common plant facilities?

These questions will be answered in the Project Options Screening, and the preferred sizes and configurations will be characterized in the remainder of the section.

Based on our design experience, we have made several assumptions regarding plant performance. These are the following:

Table 7-1. Biomass and WTE Plant Performance Assumptions.

Ambient Conditions	
Pressure, psia	14.6
Average Temperature, F	85
Relative Humidity, percent	60.1
Boiler Efficiency, percent	70

7.2 Assessment of Contributing Resource

There are several fuel resources of interest on Kauai. The most promising include four different types of biomass and the local municipal solid waste. These are characterized and quantified in this section.

7.2.1 Biomass

Quantity of Biomass

As summarized in Section 3.1.1, the biomass fuels of interest on Kauai are the following:

Table 7-2. Promising Biomass Fuel Resources on Kauai.

Resource	Quantity Available (dry tons/year)	Estimated Heat Content (MBtu/dry ton)	Potential Heat, MBtu/yr	Resource Probability Factor, percent	Likely Heat Available, MBtu/yr
Wood waste	35,000	14.45	505,750	33	167,000
Bagasse Fiber	18,000	16	288,000	33	95,000
Cane Trash	37,000	16	592,000	33	195,000
Banagrass	280,000	16	4,480,000	100	4,480,000

The resource quantities estimated are dependent on the viability of continued sugar production on the island and the ability of Bill Cowern (local wood plantation owner) to meet his fuel production estimates. Black & Veatch has discounted the total estimated fuel availability to account for the uncertainty of the fuel supply.

Black & Veatch has run economic sensitivity analyses based on variable fuel supply quantities to ensure that the impact of various fuel mixes is understood.

Cost of Biomass

Costs for each of the fuels described previously have been estimated based on supplier statements, past KIUC purchases, and Black & Veatch experience with biomass fuels.

- Wood waste is expected to be provided by Bill Cowern, of Kauai Mahogany. The value for this fuel is estimated to be $40/dry ton. This is a premium price compared to typical chipped wood; it reflects the opportunity cost of the supplier to make this material available as fuel rather than another use.

- The price for bagasse was estimated to be $25/ton, as received.
- There is not a well established market from which to derive the cost of cane trash. The price of $25/dry ton for bagasse is used as a proxy because similar collection costs are expected.
- A range of prices is used for banagrass including $70, $80 and $90/dry ton. This reflects various hauling distances and crop productivity in different areas. Black & Veatch has derived these costs through recent studies of this fuel resource. Because of the large supply potential of banagrass, this cost range is considered to act as cap for the cost of biomass fuel. Alternately, the price of coal could be used as a cap because a biomass plant would be well-suited to burn coal.

A supply curve for the four previously mentioned fuels is shown in Figure 7-1.

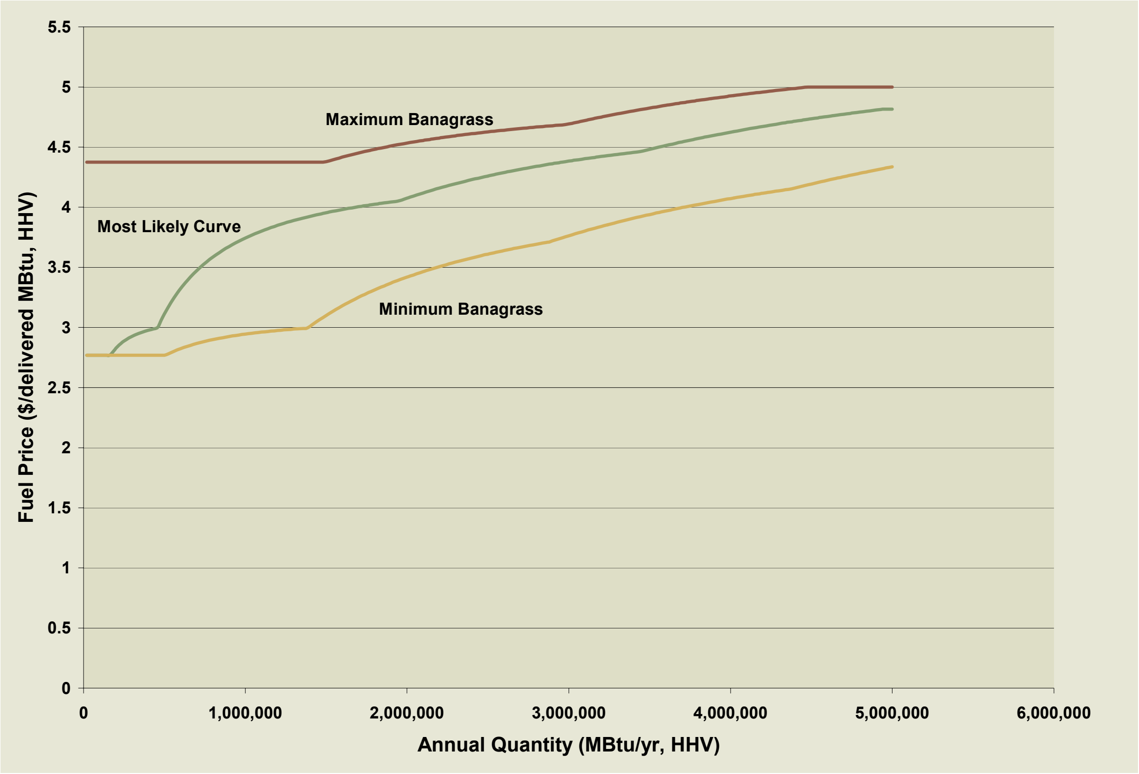

Figure 7-1 - Biomass Fuel Supply Curve

7.2.2 MSW

The composition of MSW varies by location. The most recent analysis of MSW on Kauai was performed in 1990.[67] The waste breakdown is illustrated in Figure 7-2.

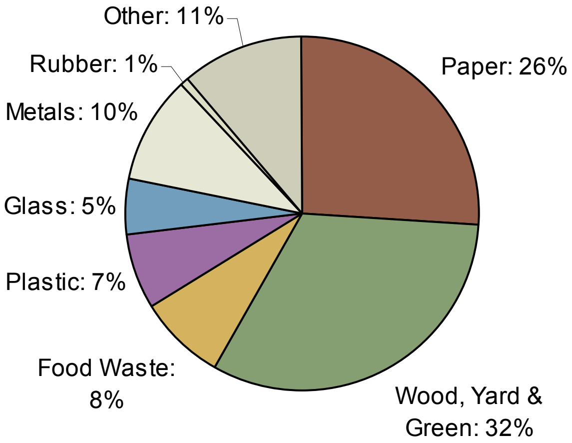

Figure 7-2. Kauai MSW Composition.

It is assumed that the moisture content of the waste stream is 35 percent. This corresponds to a higher heating value (HHV) of 11 MBtu/ton. The ash content should be approximately 10 percent, as-received.

Quantity of MSW

There is about 87,000 tons per year of MSW available. This corresponds to a daily availability of approximately 240 tons.[68] Brief analysis of Census Bureau population data and State of Hawaii per capita trash generation data validates this number. The 2003 US Census reported that there are 60,750 people living in Kauai County.[69] The State of Hawaii estimates that the per capita MSW production in Kauai County is 5.8 lb/person/day. Using the population data and the trash production averages

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[67] Dr. Robert Shleser, Ph.D., "Ethanol Production in Hawaii Report, 1994", Prepared for State of Hawaii Department of Business, Economic Development & Tourism, July, 1994

[68] Personal conversation with Troy Tanigawa, P.E., Department of Public Works, County of Kauai, on November 18, 2004.

[69] As accessed at http://quickfacts.census.gov/qfd/states/15/15007.html on November 22, 2004.

to calculate the quantity of daily MSW production results in a resource estimate of 190 tons/day, on an as-received basis.

Long term trash generation estimates can be made from population growth estimates. Based on data from the Census Bureau and the State of Hawaii, the population growth averaged 1.4 percent per year between 1991 and 2003. Escalating the reported MSW production of 240 tpd at the same rate over a period of twenty five years without changing the per capita trash production estimate results in a resource estimate of 340 tons/day, as received.

Due to uncertainties in population, economic growth, and recycling trends, the amount of MSW available in the future is difficult to predict accurately. An MSW plant could be conservatively sized to burn the 200 tpd of waste that is currently generated (enough to produce approximately 4 MW). At a 70 percent annual capacity factor, there would still be significant waste going to the landfill each year. A more aggressive target would be 300 tpd (enough for 7 MW); however, it may be necessary to burn more expensive supplemental fuel (biomass) when not enough trash is available, particularly in the early years of operation. In the worst case scenario, the plant would burn 200 tpd of waste and 100 tpd of biomass.

Cost of MSW

Tipping fees earned by accepting MSW from local waste management services are the primary source of revenue for MSW burning plants. Therefore, it is more accurate to discuss the cost of MSW as a *value* to the plant rather than a cost. The value of MSW on Kauai will be driven by political directive more than by free market pressures. Current tipping fees at the Kekaha Landfill are approximately $56/ton. However, Kekaha is nearing its permitted closure date and will likely be closed in the near term. If a new, engineered landfill is built to replace Kekaha, the cost will be paid by the citizens of Kauai through taxes and tipping fees. It has been estimated that the "all-in" tipping fee necessary to pay the cost of the new landfill will on the order of $90/ton. This data point sets a revised market price point for MSW. These two price points are used as the high and low values of MSW.

7.3 Project Option Screening

Project screening economic models were developed for stand-alone biomass and WTE facilities. Limited fuel resources constrain the project sizes to low capacities. Summaries of the individual screenings are shown below.

7.3.1 Biomass Project Screening

The primary question addressed for the stand-alone biomass configuration is scale. Although biomass plants benefit greatly from economies and efficiencies of scale, larger plants on Kauai will have higher average fuel costs. There is a limited quantity of low cost biomass resources on the island. Larger biomass plants will require the development of dedicated energy crops that are much more expensive than waste resources such as wood chips and bagasse. The figure below show some of the preliminary analyses undertaken to explore these variables. For illustration, Figure 7-3 compares the levelized busbar costs for a range of standalone biomass plant sizes using different fuel costs. Plant capacity clearly controls the busbar cost. The curve labeled "Estimated Composite" was generated by calculating the specific fuel price that is expected for each capacity output, according to the biomass fuel supply curve in Figure 7-1.

The initial conclusion is that despite higher fuel costs, larger biomass plants are more economical. Between about 20 and 30 MW the incremental improvements in levelized cost begin to slow down. Based on discussion with KIUC, it was determined that 20 MW would be the selected biomass size for detailed characterization.

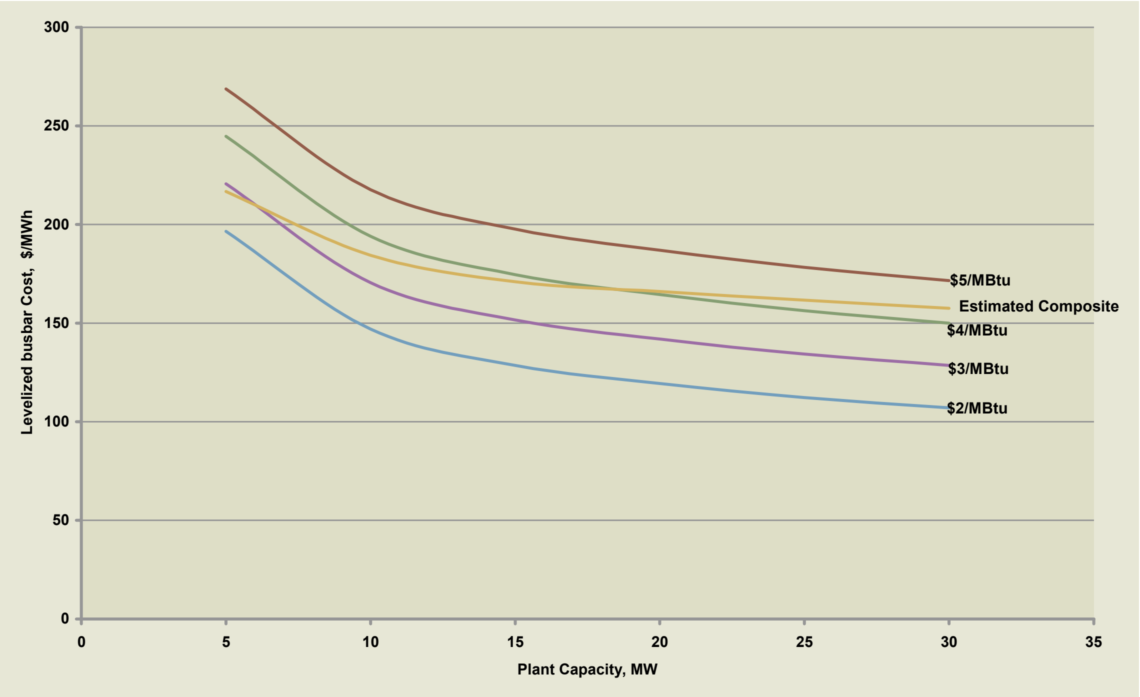

Figure 7-3. Comparative Biomass Busbar Cost with Varying Fuel Price.

7.3.2 WTE Project Screening

Scale is also the principal question for the MSW option, but only two sizes have been considered, 200 tpd and 300 tpd. As with the biomass option, the larger plant will be more efficient and have a lower capital cost per kilowatt. Further, staffing costs, a large portion of the overall O&M costs, will be similar between the two sizes. Black & Veatch modeled the two sizes. For the reasons listed above, it appears that even if there is a shortage of MSW and biomass has to be purchased, the larger plant produces lower cost energy. For this reason, it has been recommended that only the 300 tpd size be evaluated further for the Final Report.

Figure 7-4 shows two levelized busbar cost curves that are generated for various sized MSW plants with two different tipping fees. Both plant size and tipping fee strongly impact the results of the busbar cost calculation.

Figure 7-4. Comparative MSW Busbar Cost with Varying Fuel Price.

7.3.3 Combined Biomass and MSW Project Screening

At the screening level, the levelized costs for the standalone biomass and MSW projects are high. Neither project achieves a large enough capacity to take advantage of significant economies of scale. Plants of this type and size are particularly impacted by high staffing requirements. Combining the MSW and biomass in a single project is technically feasible, will better utilize staff, and has promise to offer better economic returns. There are several ways to accomplish cofiring the biomass and MSW. These options are as follows:

A. Completely separate biomass and MSW flow-lines with separate boilers and separate steam cycles
B. Separate biomass and MSW boilers together with common water and steam system
C. Processing of MSW to refuse derived fuel (RDF) plus recyclables. Feed of RDF + biomass to single boiler and steam turbine.

An alternative to the combined option would be to burn unprocessed MSW with biomass in a large mass burn boiler. However, this is not practical because mass burn boilers are inefficient and expensive compared to dedicated biomass boilers. Further, mass burn boilers require more extensive emissions monitoring and control equipment. Therefore this option has not been assessed.

Table 7-3 compares the levelized cost of the three options. Based upon these results, Option B is the better option economically. Further, it is a good solution technically. This is the option that will be modeled further in this section.

Table 7-3. Cost Characteristics of Combined Biomass & MSW Plants.

	Unit	**Option A**	**Option B**	**Option C**
Capacity	MW	26.4	26.36	26.1
Capital Cost	$/kW	5,569	5,462	5,823
First Year Fixed O&M	$/kW-yr	158	157	180
First Year Variable O&M	$/MWh	8.96	8.96	9.04
First Year Fuel Cost	$/MBtu	2.0	2.0	2.2
Net Plant Heat Rate	Btu/kWh	17,196	17,157	15,035
Levelized Cost	$/MWh	151.1	149.6	157.7

7.4 Project Technical Description

In this section, each of the technologies is described in greater detail:

- 20 MW direct fired biomass
- 300 ton per day MSW mass burn
- Combined plants on the same site with separate flow lines for biomass and MSW but common steam turbine generator and water/steam cycles

7.4.1 Biomass

Section 3.1.1 provides an overview of a typical biomass fired power station. In this section, more detail is provided. A schematic of a typical biomass power plant is provided in Figure 7-5.

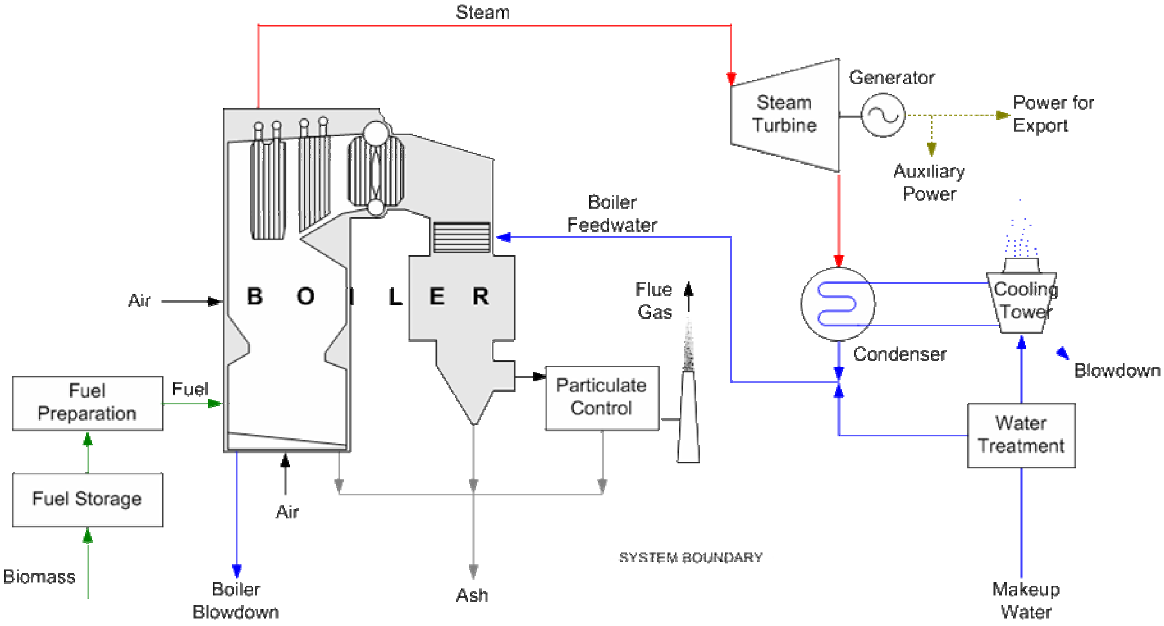

Figure 7-5. Biomass Schematic

To achieve the capacity of 20 MW, a mixture of fuels will be needed to provide the thermal input required. This fuel mixture is shown in Table 7-4.

Table 7-4. Biomass Fuel Mix Design.

Resource	**Possible Mix Scenarios**					
	Minimum Banagrass		**Most Likely**		**Maximum Banagrass**	
	MBtu/yr	Percent	MBtu/yr	Percent	MBtu/yr	Percent
Wood Waste	505,750	23	166,898	8	0	0
Bagasse Fiber	288,000	13	95,040	4	0	0
Cane Trash	592,000	27	195,360	9	0	0
Banagrass	800,746	37	1,729,199	79	2,186,496	100
	2,186,496		2,186,496		2,186,496	

Deliveries to the plant would be by standard trailers. The vehicles would be unloaded at and the fuel conveyed to storage. Storage capacity would be approximately three days supply at maximum burn rate. Fuel would be reclaimed from the store automatically and fed to the boiler. Two separate biomass material handling systems would be used to handle the diversity of fuel types. Several assumptions were made regarding the fuel processing. These are:

- Wood will be delivered chipped and boiler ready.
- Bagasse will be delivered "as processed" from the sugar mill.
- Banagrass will be delivered unprocessed and will require sizing at the plant
- Cane trash will be delivered unprocessed and will require sizing at the plant

The boiler type is assumed to be a spreader stoker with waterwalls. Slagging in the furnace would be reduced by wall mounted soot-blowers. Similarly, the convective heat transfer surfaces would also be cleaned using soot-blowers. Combustion air would be provided in two phases. Primary air would be preheated and injected under the grate. Secondary air would be preheated and injected at higher pressure higher up the furnace. Both primary and secondary air would be preheated using gas to air heat exchangers or steam to air heat exchangers. It will likely be necessary to install selective non catalytic reduction (SNCR) equipment to reduce the NOx emissions. Boiler feed water would be heated in an economizer prior to the steam drum.

Particulate control would be achieved using a baghouse. The cleaned flue gases would pass via an induced fan to a stack.

The ash content of biomass is low but there would still be a need for collection of fly ash. This would be stored and then conditioned with water prior to being sent either for disposal or for reuse as fertilizer.

Superheated steam from the boiler would be fed to a high pressure steam turbine generator. The exhaust pressure from the steam turbine would depend on the type of condenser. Steam conditions to the turbine will be 950F and 1265 psia. It is assumed that there will be four feedwater heaters. This is high for a plant this size, but it is considered prudent because the high cost of the fuel encourages high plant efficiency. The steam turbine would be complete with a number of bleedlines which would allow preheating of the boiler feed water. The condenser will be water cooled with water supply from wells. Condensate is recovered from the condenser and recycled back to the boiler via the deaerator.

The complete plant would be controlled from a control room by a fully integrated control system allowing the plant to be operated by only two staff.

7.4.2 MSW

MSW would be delivered to the plant in refuse trucks. The trucks would be unloaded in a completely enclosed bay and discharge into a refuse storage pit. Storage capacity would be approximately four days supply at maximum burn rate. MSW would be reclaimed from the pit by automatic crane and fed to the boiler. For a 300 tpd plant, it is very unlikely that modular type incinerators would be cost effective. The following description is that of a conventional mass burn incineration plant similar to hundreds of plants in the US and around the world.

A reciprocating grate suitable for mass burn application will be used for fuel feed. The furnace would be differently configured from the biomass furnace and there would be a number of differences in the gas pass because the sulfur and chlorine content of MSW are much greater than they are for biomass. This means that the acid dew point will be higher and the back end temperature at the exit from the boiler will be higher.

The ash content of MSW is much greater than that of biomass. Bottom ash is removed at the end of the grate and discharges into a wet bath system where the ash is quenched. The ash is conveyed to a silo for storage prior to being taken off site for disposal. Ash may drop out in the boiler gas pass. This ash will be added to the bottom ash for disposal.

Flue gases from the boiler would be cleaned in a set of flue gas treatment equipment. SNCR equipment will be installed in the furnace to reduce NOx emissions. Acid gas abatement would be achieved by lime injection. Heavy metals and organic pollutants would be removed using activated carbon. Particulate control would be achieved using a bag house. Fly ash removed from the baghouse would contain the products of acid gas abatement and pollution control and should be disposed of in a controlled landfill site. The cleaned flue gases would pass via an induced fan to a stack.

Steam from the boiler will pass to a condensing steam turbine generator similar to the biomass power plant described above. Due to corrosion concerns, steam conditions will be significantly lower than the biomass design: 750F and 615 psia.

7.4.3 Combined Biomass and MSW

The third category of plant for consideration comprises a combination of biomass and MSW power plants. The main benefit of bringing the two fuels to a single site is that certain parts of the facility may be combined thereby achieving economies. Options A and B had similar economics when compared during the screening phase. Option A consists of two completely separate systems for the biomass and MSW, including separate combustors and steam cycles. Option B combined the steam cycles, but maintained separate combustors for the two fuels.

Due to slightly better economics in the screening and less redundant O&M planning needs, Black & Veatch selected Option B for further analysis. A simple schematic showing this option is shown in Figure 7-6. In this arrangement, the biomass boiler operates at lower steam conditions to match the lower steam conditions for the MSW. This hurts the biomass cycle efficiency.

The combined steam from the two boilers is fed to a condensing turbine. Exhaust steam from the steam turbine generator is condensed and recirculated back through the boiler feed system.

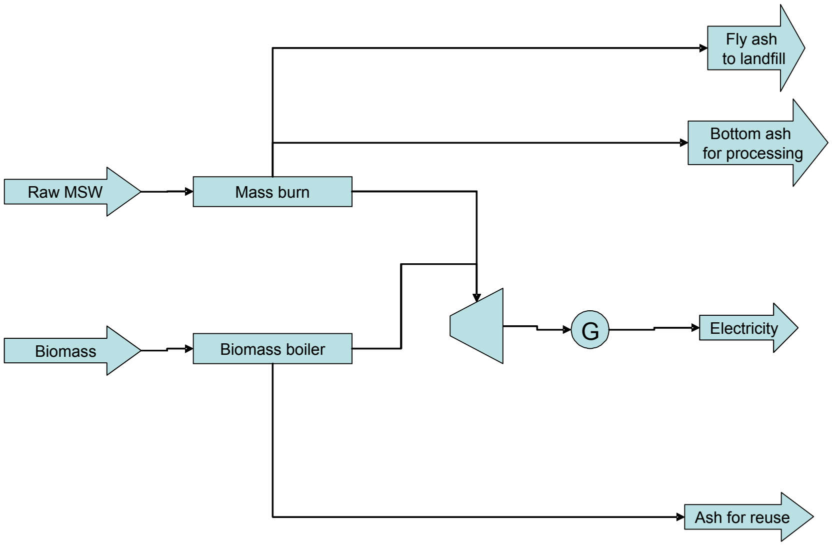

Figure 7-6. Combined Biomass and MSW Schematic

7.5 Power and Energy Production

7.5.1 Plant Performance

Black & Veatch has estimated plant performance for the three options to be as shown in Table 7-5.

Table 7-5. Comparison of Plant Performance for Biomass and MSW Options.

Performance	Standalone Biomass	Standalone MSW	Combined Option B
Gross Plant Output, kW	22,496	8,337	31,698
Aux Power, kW	2,500	1,046	3,880
Net Plant Output, kW	19,996	7,291	27,818
Fuel Burn Rate, MBtu/hr (HHV)	307.9	136.7	480.5
Gross Turbine Heat Rate, Btu/kWh	10,059	12,048	11,143
Steam Conditions, °F, psia	950, 1265	750, 615	750, 615
Net Plant Heat Rate, Btu/kWh	15,397	18,744	17,274

7.5.2 Operating Profile

It has been assumed that the plant will export power at its design rating when operational. In general it has been assumed that the availability of the power plant would be 70 percent for MSW and 80 percent for biomass.

Black & Veatch has assumed that for each flow-line there would be an annual shut of 2 to 3 weeks duration. This extended shutdown would allow the replacement or reconditioning of major items of plant such as boiler tubing etc. The balance of hours lost during the year would be unscheduled downtime.

7.6 Cost of Energy

7.6.1 Capital Cost

The estimates of capital cost for each of the three options are summarized in Table 7-6.

Table 7-6 Capital Cost Estimates

	Biomass	MSW	Combined
Equipment Contracts	$16,946,917	$12,310,231	$23,915,828
Furnish and Erect Contracts	$31,997,446	$25,282,494	$64,784,436
Construction Contracts	$24,222,334	$25,409,768	$31,730,932
Total Direct Costs	$73,166,696	$63,002,493	$120,431,197
Indirect Costs	$17,154,174	$18,900,748	$28,261,331
Land Cost	$800,000	$800,000	$800,000
Total Capital Cost	**$ 91,120,870**	**$82,703,240**	**$149,492,528**

Indirect costs have been estimated to be about 30 percent of direct capital costs.

7.6.2 Operating Cost

Operating costs have been estimated for all three options. Fixed and variable costs have been estimated for each of the options. Fixed costs include the following:

- Manpower, which is a function of the number of staff, which in turn is dependent on the size and complexity of the plant
- Insurance, which is related to the capital cost of the power block
- Administration, which depends on the number of staff

Variable costs include the following:

- Maintenance materials, which depends on the station output
- Consumables, which are directly related to station output

The following assumptions were used in calculating the fixed and variable costs.

Table 7-7. Assumptions for O&M Costs.

Annual loaded salary	$90,000/head
Insurance	0.1% of power block capital cost
Quicklime cost	$250/ton
Activated carbon cost	$2.50/lb
Urea	$225/ton
Start up fuel	No. 2 fuel oil
Cost of oil	$7/MBtu
Administration rate	10% of staff costs

The following table summarizes the fixed and variable costs associated with the biomass power plants.

Table 7-8. Biomass and MSW Plant O&M Cost Estimates.

	Biomass	MSW	Combined
FOM $/kW-yr	150	286	137
$/yr	3,004,000	2,086,000	3,808,000
VOM $/MWh	8.43	23.14	13.86
$/yr	1,182,000	1,184,000	2,610,000
Total $/MWh	29.88	64.65	34.08
$/yr	4,187,000	3,307,000	6,418,000

7.6.3 Applicable Incentives

There are several federal incentives available for the development of biomass power generation facilities. The federal production tax credit provides a $9/MWh incentive for five years following the initial commercial operation date for plants using open-loop biomass and municipal solid waste fuels. For plants utilizing closed-loop biomass fuels, the production credit is equal to $18/MWh for ten years following the initial commercial operation date. The tax code also offers a five year depreciation cycle for biomass facilities below 80 MW for facilities burning at least 50 percent biomass by heat input. For facilities above 80 MW, a seven year cycle is available. For the life-cycle cost analysis, the PTC and reduced depreciation cycle are included in the developer ownership scenario. Various federal grants and low interest loan programs would be applicable to these projects; however, the exact impact of these programs is uncertain and not quantified at this time. Therefore, no incentives are included for the KIUC ownership scenario in the life-cycle cost analysis.

7.6.4 Life-cycle Economics

Due to biomass and MSW fuel characteristics on Kauai, the life-cycle costs of projects utilizing each of these fuels will be analyzed in this section, in addition to a facility utilizing both of these fuels. Table 7-9 provides the project performance and economic assumptions and results of the life-cycle cost analysis for three fuel price scenarios. Figure 7-7 shows an example of the 25-year busbar cost calculation for the biomass plant.

Table 7-9. Biomass Life-Cycle Economic Assumptions ($2005).

	Unit	Low Fuel Cost	Mid Fuel Cost	High Fuel Cost
Capacity	MW	20.0	20.0	20.0
Capital Cost	$/kW	4,556	4,556	4,556
First Year Fixed O&M	$/kW-yr	150	150	150
First Year Variable O&M	$/MWh	8.4	8.4	8.4
First Year Fuel Cost	$/MBtu	3.50	4.15	4.57
Net Plant Heat Rate	Btu/kWh	15,397	15,397	15,397
Capacity Factor	percent	80%	80%	80%
KIUC Levelized Cost	2009$/MWh	179.5	194.8	204.6
KIUC Premium*	2009$/MWh	5.6	20.9	30.7
Developer Levelized Cost	2009$/MWh	202.8	217.0	226.1
Developer Premium*	2009$/MWh	28.9	43.1	52.2

*Electricity cost premium (or savings) compared to KIUC's forecasted avoided costs.

Based on the assumptions shown in Table 7-9, the levelized cost of electricity can be calculated. The levelized electricity cost includes all costs to generate power (capital, O&M, fuel, etc.) levelized over the life cycle of the project. In 2009, it is projected that the levelized cost of supplying power from a biomass fueled power station would range from $180/MWh to $205/MWh, depending on the fuel cost. This cost can be compared to the cost of KIUC's existing resources and projected new unit additions. These costs would be "avoided" if the biomass plant were built. Based on avoided cost forecasts from KIUC, biomass is able to avoid $174/MWh in energy and capacity costs on a levelized basis (2009$). Taking these costs into account, the premium cost for biomass ranges from $5.6/MWh to $31/MWh above avoided costs. The biomass power station does not compare favorably with the forecasted avoided costs because the fuel is expensive, the plant is relatively inefficient, and the capital costs are high. The costs are slightly higher when assuming developer financing for the project.

The levelized cost for biomass is higher than the range predicted in the first phase of the report (up to $186/MWh, see Table 3-1). The technology screening was done at a high level resulted in very broad, generic estimates of cost. As biomass was investigated in more detail, there were several changes that drove up the estimated cost of the facility. These include examining a smaller size, adding capability to burn multiple fuels, higher fixed O&M costs (largely labor), slightly poorer efficiency, and other factors. These factors combined to raise the price range of biomass outside of initial expectations.

Table 7-10 presents a summary of MSW combustion project performance and economic assumptions in addition to the results of the life-cycle cost analysis for three tipping fee scenarios. Figure 7-8 shows an example of the 25-year busbar cost calculation for the MSW fueled plant.

Table 7-10. MSW Life-Cycle Economic Assumptions ($2005).

	Unit	$56/ton Tipping Fee	$70/ton Tipping Fee	$90/ton Tipping Fee
Capacity	MW	7.3	7.3	7.3
Capital Cost	$/kW	11,343	11,343	11,343
First Year Fixed O&M	$/kW-yr	286.0	286.0	286.0
First Year Variable O&M	$/MWh	23.1	23.1	23.1
First Year Fuel Cost	$/MBtu	(5.09)	(6.36)	(8.18)
Net Plant Heat Rate	Btu/kWh	18,744	18,744	18,744
Capacity Factor	percent	70%	70%	70%
KIUC Levelized Cost	2009$/MWh	108.66	72.38	20.39
KIUC Premium	2009$/MWh	(68.00)	(104.28)	(156.27)
Developer Levelized Cost	2009$/MWh	212.83	179.26	131.16
Developer Premium	2009$/MWh	36.17	2.60	(45.50)

The range of tipping fees was selected to account for the current tipping fees at the Kekaha landfill (low), and estimated costs of disposal at a new landfill (high). The table shows that the relatively high cost of constructing and operating a waste-to-energy facility is compensated for by the high tipping fees paid to the plant to accept waste. The levelized cost of energy generation with KIUC ownership ranged from a very low $20/MWh to $109/MWh, depending on tipping fee assumptions. Compared to KIUC's forecasted avoided costs, the cost premium ranged from ($156)/MWh to ($68)/MWh. Consistent with the analysis of other technologies, the levelized cost to generate power from this project assuming developer ownership was much higher than that for KIUC ownership. Again, this can be attributed to low cost KIUC financing.

Table 7-11 presents the project performance and economic assumptions in addition to the results of the life-cycle cost analysis for three fuel cost scenarios for the combined MSW/Biomass fueled power station.

Table 7-11. MSW/Biomass Life-Cycle Economic Assumptions ($2005).

	Unit	High Fuel Cost	Mid Fuel Cost	Low Fuel Cost
Capacity	MW	27.8	27.8	27.8
Capital Cost	$/kW	5,374	5,374	5,374
First Year Fixed O&M	$/kW-yr	137.0	137.0	137.0
First Year Variable O&M	$/MWh	13.9	13.9	13.9
First Year Fuel Cost	$/MBtu	1.91	1.33	0.37
Net Plant Heat Rate	Btu/kWh	17,274	17,274	17,274
Capacity Factor	percent	77%	77%	77%
KIUC Levelized Cost	2009$/MWh	165.99	150.72	125.45
KIUC Premium	2009$/MWh	(8.66)	(23.93)	(49.21)
Developer Levelized Cost	2009$/MWh	199.56	185.43	162.05
Developer Premium	2009$/MWh	24.91	10.78	(12.60)

A range of fuel cost scenarios was developed to test the economics of the MSW/Biomass fueled power station. The high fuel cost scenario includes lowest tipping fee price and the highest biomass fuel price, the mid scenario includes the mid prices for both fuels, and the low fuel cost scenario includes the highest tipping fee price and the lowest biomass fuel price. The levelized cost for these scenarios ranged from about $125/MWh to $166/MWh, while the premium ranged from ($49)/MWh to about ($9)/MWh. As was the case with the biomass fueled plant, the higher cost of generating power with this project, relative to the other renewable energy projects, is due to the high capital cost and high heat rate. However, even under the highest fuel price scenario this project still yielded savings relative to KIUC's forecasted avoided costs.

Biomass Plant Mid Cost

Biomass

Plant Input Data		Economic Input Data	Rate	Escalation
Capital Cost ($1,000)	102,540	First Year Fixed O&M ($1,000)	3,375.85	3.0%
Total Net Capacity (MW)	20.00	First Year Variable O&M ($1,000)	1,329.58	3.0%
Capacity Factor	80%	Fuel Rate ($/MWh)	4.67	3.0%
Full Load Heat Rate, Btu/kWh (HHV)	15,397.00			
Debt Term	25			
Project Life	25			
		Present Worth Discount Rate	5.0%	
Hours per Year	8,760	Levelized Fixed Charge Rate	7.10%	

Year	Annual Capital Cost ($1,000)	Fixed O&M ($1,000)	Variable O&M ($1,000)	Fuel Rate ($/MBtu)	Fuel Cost ($1,000)	Total Cost ($1,000)	PW Total Cost ($1,000)	Busbar Cost ($/MWh)	PW Cost ($/MWh)	Avoided Capacity Cost ($/kW)	Avoided Energy Cost ($/MWh)
2009	7,275	3,376	1,330	4.67	10,078	22,059	21,008	157.41	149.92	0.00	111.89
2010	7,275	3,477	1,369	4.81	10,380	22,502	20,410	160.58	145.65	0.00	121.46
2011	7,275	3,581	1,411	4.96	10,692	22,959	19,833	163.84	141.53	0.00	131.10
2012	7,275	3,689	1,453	5.10	11,012	23,430	19,276	167.20	137.55	0.00	133.40
2013	7,275	3,800	1,496	5.26	11,343	23,914	18,737	170.66	133.71	0.00	139.93
2014	7,275	3,914	1,541	5.41	11,683	24,413	18,218	174.22	130.00	160.34	146.48
2015	7,275	4,031	1,588	5.58	12,034	24,928	17,716	177.89	126.42	162.00	155.09
2016	7,275	4,152	1,635	5.74	12,395	25,457	17,230	181.67	122.96	160.15	159.54
2017	7,275	4,276	1,684	5.92	12,766	26,003	16,761	185.56	119.61	192.08	155.25
2018	7,275	4,405	1,735	6.09	13,149	26,564	16,308	189.57	116.38	192.80	164.57
2019	7,275	4,537	1,787	6.28	13,544	27,143	15,870	193.70	113.25	192.35	168.47
2020	7,275	4,673	1,840	6.47	13,950	27,739	15,446	197.95	110.23	183.14	166.80
2021	7,275	4,813	1,896	6.66	14,369	28,353	15,036	202.33	107.30	203.74	163.22
2022	7,275	4,958	1,953	6.86	14,800	28,985	14,640	206.84	104.47	200.11	168.86
2023	7,275	5,106	2,011	7.07	15,244	29,637	14,256	211.49	101.73	196.32	159.73
2024	7,275	5,259	2,071	7.28	15,701	30,307	13,884	216.28	99.08	214.88	164.41
2025	7,275	5,417	2,134	7.50	16,172	30,998	13,525	221.21	96.51	202.03	166.83
2026	7,275	5,580	2,198	7.72	16,657	31,710	13,176	226.29	94.03	206.07	170.16
2027	7,275	5,747	2,264	7.95	17,157	32,443	12,839	231.52	91.62	210.19	173.57
2028	7,275	5,920	2,331	8.19	17,672	33,198	12,512	236.91	89.29	214.40	177.04
2029	7,275	6,097	2,401	8.44	18,202	33,976	12,195	242.46	87.03	218.68	180.58
2030	7,275	6,280	2,473	8.69	18,748	34,777	11,888	248.17	84.84	223.06	184.19
2031	7,275	6,468	2,548	8.95	19,310	35,602	11,591	254.06	82.71	227.52	187.87
2032	7,275	6,663	2,624	9.22	19,890	36,452	11,302	260.12	80.66	232.07	191.63
2033	7,275	6,862	2,703	9.49	20,486	37,327	11,023	266.37	78.66	236.71	195.46

Levelized Bus-bar Cost, $/MWh	**194.77**
Net Levelized Cost ($1,000)	**27,294.10**
Levelized Avoided Capacity Cost, $/MWh	**19.34**
Levelized Avoided Energy Cost, $/MWh	**154.56**
Levelized Cost Premium, $/MWh	**20.87**

Figure 7-7. Biomass Plant 25-Year Busbar Cost Calculation.

MSW Plant (High Tipping Fee)

MSW

Plant Input Data		Economic Input Data	Rate	Escalation
Capital Cost ($1,000)	93,082	First Year Fixed O&M ($1,000)	2,346.94	3.0%
Total Net Capacity (MW)	7.29	First Year Variable O&M ($1,000)	1,164.40	3.0%
Capacity Factor	70%	Fuel Rate ($/MWh)	-9.21	3.0%
Full Load Heat Rate, Btu/kWh (HHV)	18,744.00			
Debt Term	25			
Project Life	25			
		Present Worth Discount Rate	5.0%	
Hours per Year	8,760	Levelized Fixed Charge Rate	7.10%	

Year	Annual Capital Cost ($1,000)	Fixed O&M ($1,000)	Variable O&M ($1,000)	Fuel Rate ($/MBtu)	Fuel Cost ($1,000)	Total Cost ($1,000)	PW Total Cost ($1,000)	Busbar Cost ($/MWh)	PW Cost ($/MWh)	Avoided Capacity Cost ($/kW)	Avoided Energy Cost ($/MWh)
2009	6,604	2,347	1,164	(9.21)	(7,715)	2,400	2,286	53.69	51.13	0.00	111.89
2010	6,604	2,417	1,199	(9.48)	(7,947)	2,274	2,063	50.87	46.14	0.00	121.46
2011	6,604	2,490	1,235	(9.77)	(8,185)	2,144	1,852	47.96	41.43	0.00	131.10
2012	6,604	2,565	1,272	(10.06)	(8,431)	2,011	1,654	44.97	37.00	0.00	133.40
2013	6,604	2,642	1,311	(10.36)	(8,684)	1,873	1,467	41.89	32.82	0.00	139.93
2014	6,604	2,721	1,350	(10.67)	(8,944)	1,731	1,292	38.71	28.89	160.34	146.48
2015	6,604	2,802	1,390	(10.99)	(9,212)	1,585	1,126	35.44	25.19	162.00	155.09
2016	6,604	2,886	1,432	(11.32)	(9,489)	1,434	971	32.07	21.71	160.15	159.54
2017	6,604	2,973	1,475	(11.66)	(9,774)	1,279	824	28.61	18.44	192.08	155.25
2018	6,604	3,062	1,519	(12.01)	(10,067)	1,119	687	25.03	15.37	192.80	164.57
2019	6,604	3,154	1,565	(12.37)	(10,369)	955	558	21.35	12.48	192.35	168.47
2020	6,604	3,249	1,612	(12.74)	(10,680)	785	437	17.56	9.78	183.14	166.80
2021	6,604	3,346	1,660	(13.13)	(11,000)	611	324	13.66	7.24	203.74	163.22
2022	6,604	3,447	1,710	(13.52)	(11,330)	431	218	9.63	4.87	200.11	168.86
2023	6,604	3,550	1,761	(13.93)	(11,670)	245	118	5.49	2.64	196.32	159.73
2024	6,604	3,656	1,814	(14.34)	(12,020)	55	25	1.22	0.56	214.88	164.41
2025	6,604	3,766	1,869	(14.77)	(12,381)	(142)	(62)	-3.17	-1.38	202.03	166.83
2026	6,604	3,879	1,925	(15.22)	(12,752)	(344)	(143)	-7.70	-3.20	206.07	170.16
2027	6,604	3,996	1,982	(15.67)	(13,135)	(553)	(219)	-12.36	-4.89	210.19	173.57
2028	6,604	4,115	2,042	(16.14)	(13,529)	(767)	(289)	-17.16	-6.47	214.40	177.04
2029	6,604	4,239	2,103	(16.63)	(13,935)	(988)	(355)	-22.11	-7.94	218.68	180.58
2030	6,604	4,366	2,166	(17.13)	(14,353)	(1,216)	(416)	-27.20	-9.30	223.06	184.19
2031	6,604	4,497	2,231	(17.64)	(14,783)	(1,451)	(472)	-32.45	-10.57	227.52	187.87
2032	6,604	4,632	2,298	(18.17)	(15,227)	(1,693)	(525)	-37.86	-11.74	232.07	191.63
2033	6,604	4,771	2,367	(18.72)	(15,684)	(1,941)	(573)	-43.42	-12.82	236.71	195.46

Levelized Bus-bar Cost, $/MWh	**20.39**
Net Levelized Cost ($1,000)	**911.62**
Levelized Avoided Capacity Cost, $/MWh	**22.10**
Levelized Avoided Energy Cost, $/MWh	**154.56**
Levelized Cost Premium, $/MWh	**(156.27)**

Figure 7-8. MSW Plant 25-Year Busbar Cost Calculation.

7.7 Advantages and Disadvantages

7.7.1 Fit to KIUC Needs

Biomass and MSW do not fit well with KIUC's current needs. They are both larger capacity, baseloaded technologies. In the longer term, either one could fit well with KIUC's capacity expansion needs.

7.7.2 Environmental Impact

The solid-fuel biomass industry provides substantial environmental and social benefits associated with its collection and tightly controlled combustion of biomass, thereby avoiding the environmentally less desirable disposal alternatives (such as open-field burning of cane trash). As primarily a waste management industry that generates electricity almost as a by-product, the biomass industry provides numerous environmental and social benefits. However, biomass power costs more to generate than conventionally fueled power as a result of the smaller plant sizes required, and the additional costs associated with collecting, processing, and transporting the fuel.

The environmental benefits provided by the biomass industry are a public good, which is seldom if ever paid for by individual citizens. The support for public good projects is a policy issue, and is usually implemented by the government. The biomass industry benefits to the environment are:

- **Air Quality and Acid Precipitation** – Fossil fuel and biomass combustion both result in sulfur and nitrogen emissions that can contribute to acid deposition, reduced visibility due to haze, and ground level ozone formation. However, biomass feedstocks contain relatively little sulfur and varying amounts of nitrogen. Sulfur emissions from biomass-fired facilities without sulfur emissions controls are similar to those from fossil fuel facilities that have such controls. Nitrogen emissions from biomass-fired facilities depend on the conversion process and the nitrogen content of the biomass. Except for some feedstocks from the waste stream that are contaminated with paints and preservatives, biomass feedstocks contain relatively low levels of toxic metals such as mercury, cadmium, and lead. The proposed facility is planning on using clean biomass; therefore, toxic metals should not be released.
- **Global Climate Change** – Biomass power is viewed as a carbon-neutral power generation option. While carbon dioxide is emitted during biomass combustion, an equal amount of carbon dioxide is absorbed from the atmosphere during the biomass growth phase. Thus, biomass fuels "recycle" atmospheric carbon, minimizing global warming impacts.
- **Reduction in Landfill Needs** – Reduction in waste management costs as a result of lessened load on landfills and reduced requirement for new landfill development. Generation of greenhouse gases from decomposition, particularly methane, is reduced. The implementation of new USEPA standards to control emissions of volatile organic compounds (VOCs) has increased the cost and difficulty of adding new landfill capacity in the United States. Tipping fees have increased, and to conserve existing landfill capacity many landfill operators no longer accept wood, leaves, or grass clippings.
- **Less Ash** – Biomass combustion results in less ash per Btu than coal, reducing ash disposal costs and landfill space requirements. Depending on local

regulations, most biomass ash can be used as a beneficial soil amendment for farmland, further reducing the burden on landfills.

7.7.3 Socioeconomic Impacts

The socioeconomic impacts of any of the three cases would be very high. The standalone biomass plant would support a new agriculture crop as well as help sustain the remaining sugar industry. The MSW project would substantially alleviate pressures to build or expand landfill capacity on the island. The combined plant would allow both benefits to be realized.

All three projects would create a significant amount of employment for fuel processing, plant operation, and initial construction.

7.7.4 Incentives and Barriers

Biomass

Kauai has several biomass power plants operating in its history, including the currently operating facility at the Gay and Robinson sugar mill The technology is accepted and integrates well into the agricultural economy of the island. Because of the existing plants, there are experienced operators and maintenance staff who could be utilized to run the plant. Several landowners and industry members have expressed interest in seeing a biomass project developed. It offers potential markets for their crops or residues.

There is general public opposition to biomass power plants because they rely on combustion and look similar to coal plants. NIMBY attitudes can prevail against biomass projects despite the fact they generate renewable energy.

MSW

Building an MSW project on the island would significantly alleviate the waste disposal issues that are currently being discussed. There should be local experience with MSW power generation because of the close proximity of H Power near Honolulu. Kauai possesses the unique combination of land constraints and elevated avoided generation costs that can make MSW projects look economically appealing. Portions of the community favor such a project.

Potential sources of public-health risk include human exposure to contaminants emitted from waste-to-energy facilities to the ambient air and water, as well as exposure to disease vectors such as insects and rodents. Principal sources of potential risk to public safety include explosions during operations and increased traffic hazards associated with facility-related trucks. Sources of environmental risks include truck contributions to traffic congestion; process and truck-related noise; discharge of effluents into surface and groundwater; aesthetic impairments, such as land use incompatibility, and dust. Many of these risk factors also apply to the biomass option.

MSW projects typically have opposition on the grounds of public health. In the past, MSW projects did not have strong emissions controls and they were seen as very polluting. The US EPA has tightened emission requirements for new MSW projects and many of those concerns are no longer factually validated. However, public opposition remains strong, in many cases.

7.8 Recommended Next Steps

Although biomass does not compare well economically with some of the other technologies and projects reviewed in this study, it may be a good fit for KIUC in the long term when capacity is needed. With an eye to the future, there are several activities that could be performed that would prepare KIUC for the possibility for adding biomass capacity in the ten year planning horizon. These are the following:

7.8.1 Fuel Property Testing

There is wide variety in biomass fuel properties based on species and growing and harvest conditions. Some biomass fuels, such as pulp wood chips, are well-characterized by the power industry. Others, like albizzia, are less known and understood. This study has identified several resources which would be significant constituents of a future biomass power fuel mix. For a relatively small cost, representative samples of these resources could be tested for important fuel properties such as heating value, ash content, alkali, and others. Having this information will assist in determining the best fuel mix and laying the groundwork for making these fuel resources available.

7.8.2 Banagrass Crop Productivity Study

Banagrass is an energy crop that grows well in Hawaii. Considerable effort has been expended on other islands investigating the potential of banagrass as a significant fuel resource for future power generation. A similar study on Kauai would identify suitable areas for raising banagrass crops, expected productivities and delivered fuel costs.

7.8.3 Site Studies

Siting solid fuel plants is always complex. Issues that must be considered include land use, endangered species, viewsheds, waste disposal, cooling water sources, transmission, fuel delivery and others. Conducting preliminary siting studies will identify promising candidate sites and allow a headstart in securing land access, permitting and fuel supply. When a list of the most likely sites is developed, more detailed studies can be conducted to determine which site is best suited for project development.

7.8.4 Letter of Intent for Fuel Supply

Completion of the previous three tasks will enable KIUC to begin negotiations for fuel supply. The first step is to secure a commitment by potential fuel suppliers to provide a consistent stream of fuel that can be the basis for further project design. Without LOIs for fuel supply, the project concept cannot be further developed.

7.8.5 Permitting Review

A permitting review will identify all of the permits required to construct and operate a new facility. It will also identify fatal flaws in the project concept arising from permitting issues. This low cost permitting activity will layout the road map for development of a new biomass or MSW power project.

7.8.6 Determination of Landfill Closure Date and Long Term Waste Disposal Strategy

Specific to the MSW project option, it is critical to understand the planning and politics of the current landfill closure and construction of a new landfill. An MSW project needs to be proposed and added to the list of engineering options for waste disposal before the community decides that building a new landfill is the only option available. The economics of an MSW project are competitive if the tipping fee is high enough.

7.8.7 Feasibility Study and Conceptual Design

A feasibility study would incorporate all of the previous tasks into a thorough opinion of the viability of a biomass or MSW plant. Detailed analysis or technical and economic issues would be performed and documented in the study.

If a project were determined to be feasible, a conceptual design phase would be performed to determine the basis for major systems including fuel handling, boiler, steam turbine, heat rejection and emission controls. More accurate opinions of cost and plant performance would be developed from this conceptual design to validate the findings of the feasibility study prior to detailed design and further project development efforts.

8.0 Hydro

Hydroelectric power captures the kinetic energy of water as it moves from a high elevation to a lower elevation by passing it through a turbine. The amount of kinetic energy captured by a turbine is dependent on the head (distance the water is falling) and the flow rate of the water.

Hydropower is typically associated with capturing energy in natural watercourses as they flow towards the sea. However, other creative schemes, such as pumped storage using saltwater and capturing groundwater have been proposed, even on Kauai. One scheme proposed in the 1940's considered diverting water trapped in Kauai's basalts for hydropower generation.[70]

Often, water is raised to a higher potential energy by blocking its natural flow with a dam. Projects that store large amounts of water behind a dam regulate the release of the water through turbines over time and generate electricity regardless of the season. These facilities are generally base loaded. Pumped storage hydro plants pump water from a lower reservoir to a reservoir at a higher elevation where it is stored for release during peak electrical demand periods.

Another method of capturing the kinetic energy is to divert the water out of the natural or artificial waterway, through a penstock and back to the waterway. Such "run-of-river" or "run-of-ditch" applications allow for hydroelectric generation without the impact of damming the waterway. Often resources of adjacent drainage basins are diverted to increase the total flow, and thus power production.

The existing worldwide installed capacity for hydroelectric power is by far the largest source of renewable energy at 740,000 MW. However, for reasons discussed later in this section, many environmental groups object to the broad definition of hydroelectric resources as renewable. Numerous classification systems for hydro have developed in an attempt to distinguish "renewable" projects. Generally this distinction is based on size, although "low-impact," low-head, and run-of-river plants are also often labeled renewable. Size classifications for smaller hydro systems include:

- Micro - up to 100 kW
- Mini - 100 kW to 1.5 MW
- Small - 1.5 MW to 30 MW

Because of the limited geographic extent and population base on Kauai, all existing and proposed hydroelectric projects fall into these three categories.

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[70] Orion Engineering, Inc., Wainiha Hydroelectric Project Environmental Impact Statement, Volume II, prepared for McBryde Sugar Company, August 1983, p. 127.

8.1 Basis for Assessment

Hydropower potential for Kauai was assessed based on information available in numerous public reports provided by KIUC, other individuals, or available on the internet. These reports are referenced throughout this section. Current information on the status of potential projects and attitudes toward hydropower development were based on conversations with individuals associated with hydropower development on the island.

Studies completed by the Department of Energy have evaluated hydropower potential in Hawaii on a regional basis based on general rainfall and topography.[71] However, even screening level studies have to be based on site specific input because of the complex interrelationship between rainfall, topography, geology and water use. Because of this, more than other types of renewable energy sources, hydro project costs and feasibility are very site specific. The assessment of hydro potential was therefore based largely on published reports by the federal government, state government, and private developers looking at specific project sites.

In order to supplement information found in the reports with current activity and perceptions, telephone contacts were initiated with the following individuals:

- Dennis Watt, U.S. Bureau of Reclamation, Boulder City, NV
- Laurie Ho, Natural Resource Conservation Service, Lihue, Kauai
- Mina Morita, District 12 State Representative, Honolulu, Oahu
- Maria Tome, Alternative Energy Engineer, State of Hawaii, DBEDT
- David Rezachek, Consultant/former DBEDT
- Mike Kido, University of Hawaii Center for Conservation Research & Training
- Jerry Ornellas, President, East Kauai Water Users Cooperative
- Jeff Deren and Joe McCawley, KIUC, Lihue, Kauai
- Charlie Okomoto, Finance Director, Gay & Robinson, Kaumakani, Kauai
- Owen Moe, Engineer, Gay & Robinson, Kaumakani, Kauai
- Randy Hee, former McBryde Sugar engineer, Kekaha, Kauai
- John Wehrheim, Pacific Hydro, Kauai
- Brent Smith, Northwest Power (Symbiotics), Rigby, ID
- Kearon Bennett, Ottawa Engineering Limited, Ottawa, Ontario, Canada

Maria Tome, Mike Kido, Jerry Ornellas, John Wehrheim and Kearon Bennett were unavailable for comment.

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[71] U.S. Department of Energy Report DOE/ID-11111, "Water Energy Resources of the United States with Emphasis on Low-Head/Low Power Resources," April 2004.

8.2 Assessment of Contributing Resource

The flow of water in a river basin is largely a function of size, topography and climate. In many respects, Hawaii, and Kauai in particular, is an ideal location for development of hydropower resources because it is endowed with hydropower's two main needs: precipitation and elevation drop. Due to the island's small size, tributary drainage areas are small, which is not typically ideal for hydropower. Nevertheless, on Kauai, basins are often productive hydrologically due to their topography and rainfall.

8.2.1 Topography

The conical topographical shapes produced by the volcanic origins of Hawaii result in relatively steep gradients from the volcano crater to the ocean. In general, this is a benefit for hydropower. Hydropower is most economical when there are drops in elevation of hundreds of feet in short distances since penstock and access costs as well as hydraulic head losses are a function of distance. For run-of-river projects, often volcanic slopes do not have gradients steep enough to result in economical projects. Fortunately, Kauai has the advantage of being the oldest of the major Hawaiian Islands. The forces of erosion have over time created steeper canyons where high short drops in topography are available. The Waimea Canyon is one such location. Waterfalls abundant on Kauai provide another "natural" location to derive benefits from hydropower.

8.2.2 Rainfall

The summit of Mount Waialeale on Kauai is known as "the wettest spot on earth" because of its average annual precipitation over 400 inches. Waters flowing from the summit of this mile-high mountain produce 61 perennial streams and many more intermittent streams.[72] Rainfall along the coast drops to as low as 20 inches per year.

As in other tropical climates, rainfall on Hawaii can vary greatly from year to year. In high rainfall areas, monthly averages can vary as much as 200 to 300 percent between years.[73] Monthly variation in rainfall can be seen for select stations in Figure 8-2 below. Mount Waialeale is the wettest of the rainfall stations and Makaweli on the southwest coast is the driest. The two Wainiha stations are representative of rainfall in areas of existing and proposed hydropower plants. It can be seen that dryer summer months (May through September) give way to wetter winter months (October through April), but that unlike some other parts of the United States, precipitation is generally year-round. This is useful for hydropower from the standpoint of power generation.

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[72] U.S. Fish and Wildlife Services, "Endangered and Threatened Wildlife and Plants; Designation of Critical Habitat for the Newcomb's Snail; Final Rule, 50 CFR, Part 17, August 20, 2002.

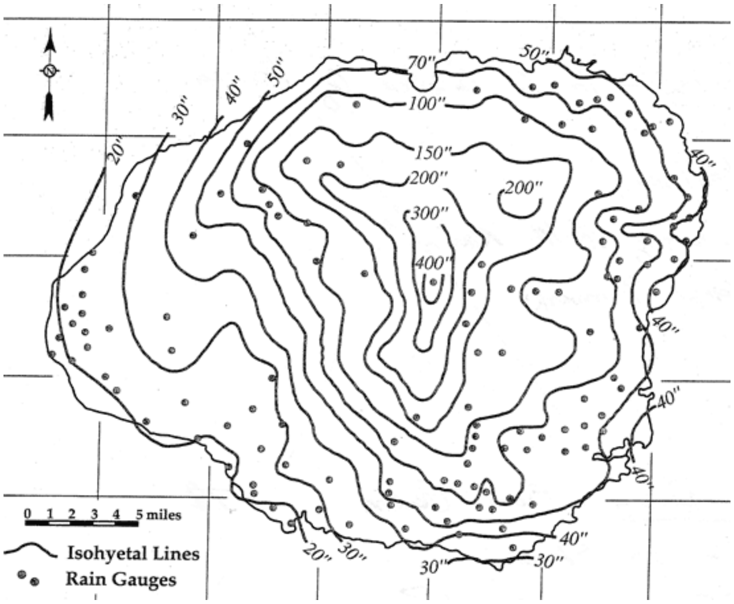

Figure 8-1. Kauai Average Annual Rainfall Map (source: http://www.balihai.com/islandinfo/kauai_maps.html).

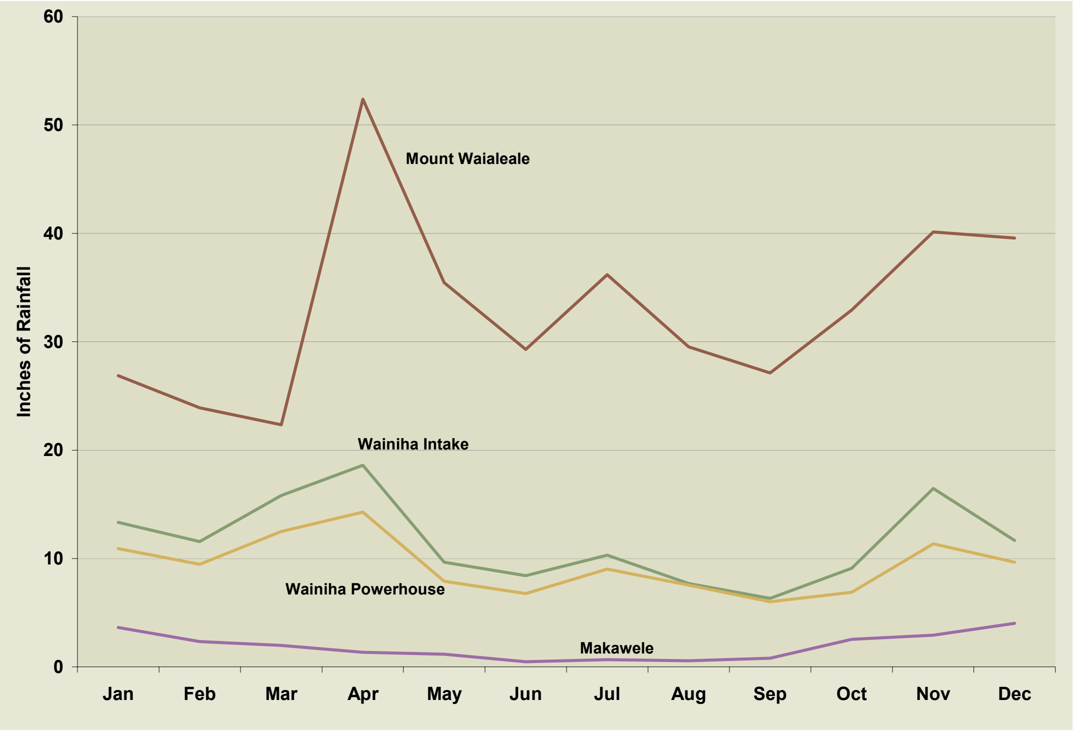

Figure 8-2. Monthly Precipitation at Select Stations in Kauai, Average 1970-2002 (Source: University of Hawaii).

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[73] National Oceanic and Atmospheric Administration, National Climactic Data Center, "Climate of Hawaii," http://www.wrcc.dri.edu/narratives/HAWAII.htm

Discrete winter storms resulting in high stream flows provide much of the total precipitation records at these rain gages. Nevertheless light showers are also quite common throughout Hawaii.[74] Rainfall in Hawaii tends to fall more at night or early morning. This diurnal variation is more pronounced during the summer than in the winter.[75] Overall rainfall patterns and geography are favorable to hydropower in Kauai, but yearly, seasonal, and daily variations will impact the consistency of power production.

Stream gaging stations is available throughout Kauai. Many of these are associated with the plantation irrigation systems where hydropower projects are likely to occur. Because the translation of existing stream flows to site specific flows requires significant effort, especially in view of the complex irrigation systems in some areas, individual stream gage data was not reviewed for this report. Flow data was based on previous studies noted herein.

An example of stream flow is shown below in Figure 8-3. The gaging station is located between the diversion and powerhouse of the proposed upper Wainiha project. As this is an uncontrolled stream, the flow curve reflects the precipitation curves for the existing Wainiha Diversion and Powerhouse in Figure 8-2.

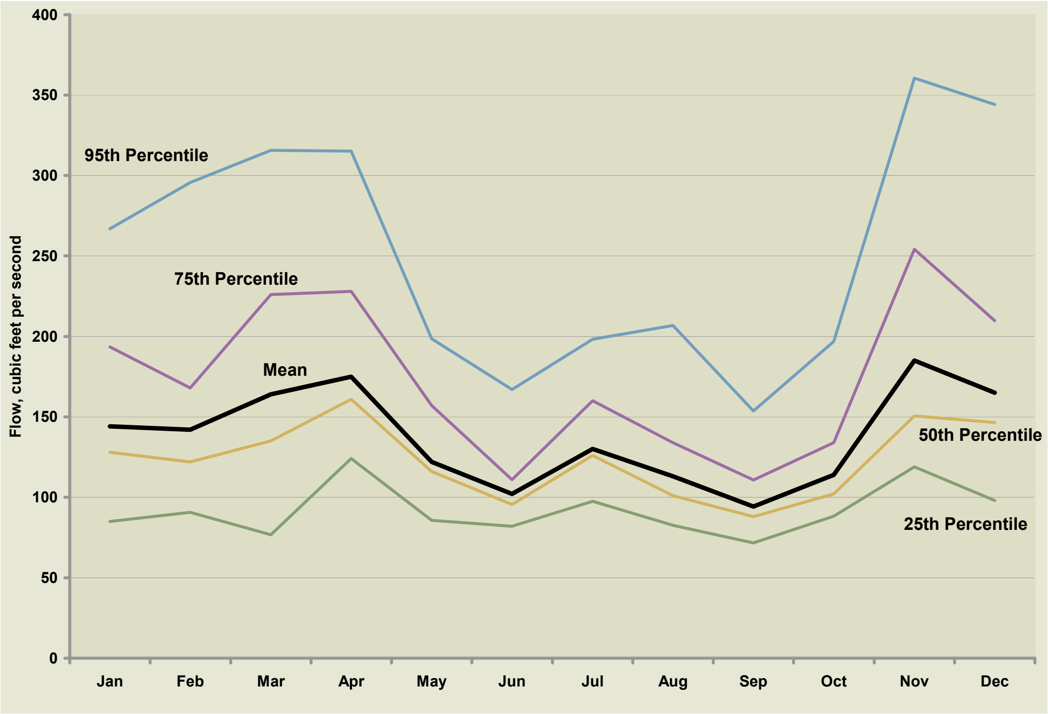

Figure 8-3. Monthly Stream Flows on Wainiha Stream (Source: USGS).

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[74] National Oceanic and Atmospheric Administration, National Climactic Data Center, "Climate of Hawaii," http://www.wrcc.dri.edu/narratives/HAWAII.htm

[75] ibid

8.2.3 Use of Water for Hydropower

Hydropower is a fully commercial technology that already makes a significant contribution to the electric supply on Kauai. The early economic development of Kauai progressed hand-in-hand with hydropower development as sugar plantations sought power to run their mills. The demise of the sugar industry in the last half of the 20th century has meant that many of the water and hydropower resources have not been economical to maintain from an agricultural standpoint. In spite of this, the seven powerhouses still account for 8.8 MW of the island's 135.8 MW of generation, or 6.5 percent.[76]

The demise of plantation agriculture presents a unique opportunity for hydropower on Kauai. The value of water can be converted from agriculture to power generation. Many existing facilities can be renovated and upgraded to make hydropower cost-competitive. Most of the existing and proposed projects fall into this category of utilizing existing irrigation resources. In cases where agriculture is still an important use for the water, water delivery systems can be developed with the flexibility to provide water for irrigation as needed while surpluses generate electricity.

The waters of the State are controlled by the State of Hawaii. Currently water use leases administered by the Department of Land and Natural Resource are for one year and are revocable.[77] During the last 20 years, no new leases have been issued for water in irrigation systems.[78] Longer-term leases are likely to be required if development of hydropower is to be financially feasible.

8.3 Project Option Screening

A total of 41 new and 8 existing projects were identified from previous reports and telephone interviews. Projects were grouped into four major regions dominated by historic agricultural use: north, east, south and southwest. A complete list of these projects is found in Appendix A. A 1978 U.S. Army Corps of Engineers (Corps) study identified four potential new projects on Kauai.[79] A 1981 Corps Study identified seven different projects including five new and two upgrade projects.[80] These Corps projects

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[76] U.S. Bureau of Reclamation, Lower Colorado Region, "Preliminary Assessment of Small Hydropower Potential on East Kauai Water Users Cooperative Lands and Other Kauai Agricultural Water Delivery Systems," prepared by Ottawa Engineering Ltd., November 2004, p. 33.

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[77] ibid, p.14.

[78] ibid, p.14.

[79] U.S. Army Corps of Engineers, Honolulu District, Summary Report for Hydroelectric Power, October 1978.

[80] U.S. Army Corps of Engineers, National Hydropower Resources Study, Regional Assessment: Alaska and Hawaii, Volume XXIII, September 1981.

were summarized by the State of Hawaii in a 1981 report.[81] Later, the US Department of Energy began a database of potential hydropower projects that currently includes eight new projects, some which were earlier identified by the Corps.[82] In fact, several of the proposed projects were variations of one another based on differing diversion points often within existing complex irrigation schemes such as in the Wailua and Kokee areas.

Of these 49 projects, a total of five projects (three new and two upgrade) were selected based on the frequency of mention, freedom from prohibitive environmental issues, and relatively high energy production based on cost. One of the projects (Kokee) has two powerhouses, resulting in six total sites. All of these projects are run-of-river or run-of-ditch, although some involve the use of existing reservoirs currently not generating hydropower. The location of these projects is shown in Figure 8-4. The five selected projects are listed in Table 8-1.

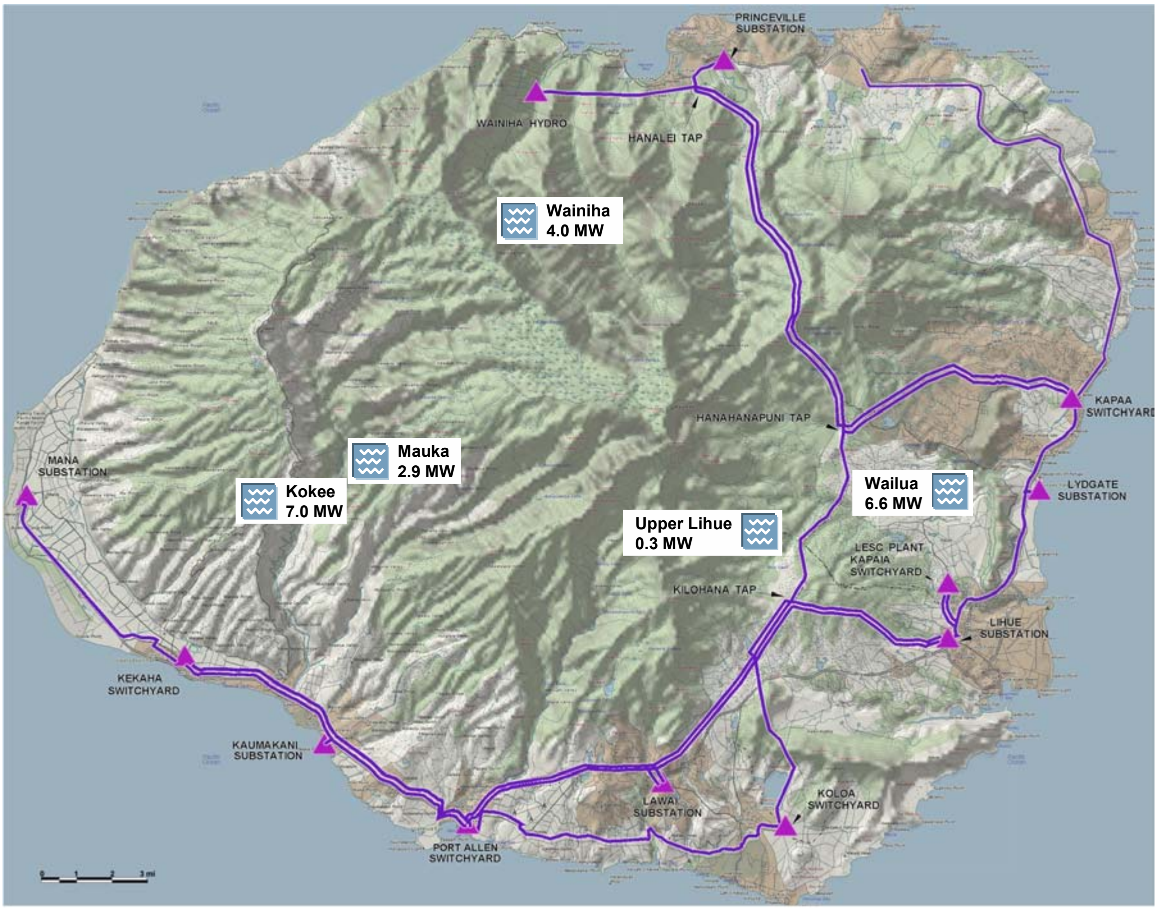

Figure 8-4. Map of Selected Hydropower Projects.

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[81] W.A. Hirai & Associates, Hydroelectric Power in Hawaii: A Reconnaissance Survey, prepared for State Department of Planning and Economic Development, February 1981.

[82] U.S. Department of Energy, Idaho National Engineering and Environmental Laboratory, Hydropower Resource Economics Database, Public Version, April 28, 2003.

Table 8-1. Selected Hydro Projects.

No.	Project Name	Status	Type	Static Head (ft)	Design Flow (cfs)	Plant Size (kW)		
						Exist.	Prop.	Total
1	Wainiha	new	run-of-river	433	139	0	4,000	4,000
2	Upper Lihue	upgrade	run-of-river	247	32	500	300	800
3	Wailua	new	run-of-river	262	150	0	6,600	6,600
4	Waimea Mauka	upgrade	run-of-river	265	55	1,000	2,900	3,900
5A	Puu Lua-Kitao	new	run-of-ditch	1,145	40	0	2,970	2,970
5B	Kitano-Waimea	new	run-of-ditch	2,093	30	0	4,078	4,078

8.4 Project Technical Descriptions

This section provides descriptions of the five projects.

8.4.1 Wainiha

The Wainiha project is on north side of the island upstream from an existing 3.6 MW powerhouse developed by the McBryde Sugar Company in 1906. The existing Wainiha powerplant is shown in Figure 8-5.

Figure 8-5. Existing Wainiha Hydropower Plant.

In the early 1980's McBryde commissioned a private study to optimize the hydropower potential based on balancing increased head moving upstream with decreased flows and increased access and penstock costs. The project was advanced to the point of completing the Environmental Impact Statement (EIS).[83] All of the necessary permits, including FERC and the Corps 404 were applied for and some state permits had already been issued. No salient biological or cultural resources created significant concern. Nevertheless, for economic reasons, McBryde Sugar abandoned the project in favor of other endeavors. Relatively low oil prices apparently made the project unattractive.

Unlike most new hydropower projects, Wainiha has not faced as much opposition partly because the stream and area have been disturbed for almost a century. The EIS points out that wildlife has flourished with the existing project. Since the new project is very similar, the same is expected. The project also has the advantage of being located in the rural north, far from the more urbanized eastern and southern portions of the island. Development of electricity in the area could improve the reliability of electrical service in an area distant from other power sources.

Access to this project is believed to be a significant factor since the highway leading to the north shore has 8- to 12-ton weight limits. Larger equipment may be transported by barge to the Wainiha Beach. The existing 4.3-mile access road from the highway to the existing powerhouse will have to be improved and well as construction of a new 2.1-mile access road.

Two other project influences are worth noting. One is that the land where the project is to be located is now owned by Kauai Coffee whose interest in the project, like those many agribusinesses, is likely to be primarily economical. Second, lands downstream from the project are cultivated in taro. Any changes occasioned by the project will need to address the needs of this traditional practice.

8.4.2 Upper Lihue

The Upper Lihue (Upper Waiahi) power plant was constructed in 1931 by the Lihue Plantation, which later sold power to Kauai Electric / KIUC as irrigation power needs declined. When Lihue Plantation ceased operation, KIUC received ownership of the plant. Due to a lack of funding for maintenance, the capacity of the conveyance system leading to the Upper Lihue power plant has been reduced from its original capacity of 25 to 30 million gallons per day (MGD) to approximately 17 MGD. The existing 36-inch penstock is believed to have been originally designed for 20 MGD, but appears to have been capable of carrying even higher flows judging by its relatively large diameter. A second footing and tailrace at the powerplant is also evidence that additional

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[83] Orion Engineering, Inc., Wainiha Hydroelectric Project Environmental Impact Statement, Volume II, prepared for McBryde Sugar Company, August 1983.

capacity was incorporated into the original design. Nevertheless the capacity of the penstock has also eroded over time due to corrosion on the inside of the steel pipe.

Recommendations for rehabilitation of the conveyance canal and power plant have been made since at least the early 1980's. The history of these recommendations are summarized in a February 2003 study by Pacific Hydroelectric Company.[84] The most recently proposed project would upgrade the plant from 500 kW to 800 kW by replacing the Iliiliula Intake trashrack, restoring the debilitated Iliiliula Flume, increasing the penstock diameter from 36 to 42 inches, and adding a 300 kW Pelton turbine at the existing powerhouse. Additional work to restore other segments of the conveyance system and increase its capacity to 32 MGD were assumed to take place in advance of this project. This additional work would include improving and restoring abandoned stream gages and adding a sluice gate to the Waioki Intake. Cost information for this project is summarized in a May 2003 Pacific Hydroelectric report.[85]

Figure 8-6. Lower Lihue Plant 800 kW Turbine.

8.4.3 Wailua

The Wailua River has been the subject of numerous studies in the last 25 years because of its productive watershed. In fact, Wailua is the only Kauai hydro project that is currently listed in the State's Renewable Energy Resource Assessment and

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[84] Pacific Hydropower Company, Upper Waiahi Hydro: Preliminary Source Investigation and Feasibility Study for a Second Turbine, prepared for Kauai Island Utility Cooperative, February 2003.

[85] Pacific Hydropower Company, Waiahi Upgrade Budgetary Cost Estimate, prepared for Kauai Island Utility Cooperative, May 2003.

Development Program.[86] The proposed 6.6 MW scheme diverts water above Wailua Falls to a downstream power plant. It has the advantage of being located in already developed areas, ensuring ready access and avoiding disturbance of pristine habitat.

In the 1980's Island Power pursued a project and completed an Environmental Impact Statement. Reportedly, development was halted not so much from overwhelming opposition to the project, but poor presentation of the project details showing knowledge of local conditions.

In 2001, Northwest Power, a hydropower developer operating under the name Symbiotics LLC, filed a Preliminary Permit Application with the Federal Energy Regulatory Commission (FERC) on the Wailua project.[87] This application was one of 250 filed by Northwest Power with FERC, but the only one in Hawaii. Concerned responses from individuals, local groups and state and federal agencies were filed shortly thereafter, primarily directed at environmental concerns. In 2004, under pressure from FERC to demonstrate progress on this application, Northwest Power, operating now under the name Pacific Energy Resources, filed a new Preliminary Permit Application for the same project. The application was accepted for filing under Project No. 12534 on December 17, 2004. Completion of the permitting process is expected to take three to five years.[88] To our knowledge, this makes Wailua the only project currently under active pursuit in Kauai.

The project addresses the primary environmental concern of diverting water above the prominent Wailua Falls by maintaining minimum instream flows of 15 cubic feet per second. Wailua Falls is widely known because of its feature in the 1978-1984 television series, *Fantasy Island.* Project components are planned to be invisible from the Wailua Falls overlook, a popular tourist destination. Portions of the project fall within Wailua River State Park.

Because the Wailua project is active, it presents a glimpse of current attitudes towards hydropower development in Kauai. Many on Kauai are in favor of renewable energy including hydropower. After a visit by the U.S. Bureau of Reclamation to a potential hydropower site near Wailua Reservoir near the Himalayan Academy, this Hindu monastery posted pictures of the visit with the comment that "a local renewable source will be a small contribution to the new world order of self-sustaining cultures."[89] Some however, will apparently be opposed to this project regardless of how development is approached. The Kauai Development Digest urges petitions to FERC against the

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[86] State of Hawaii, Department of Business, Economic Development and Tourism, Renewable Energy Resource Assessment and Development Program, 1995, updated in 2000 and 2004.

[87] Symbiotics, LLC, Lower Wailua Hydroelectric Project, FERC No. 12025, 4 pp., no data.

[88] TenBruggencate, Jan, "Proposal for dam rekindled on Kaua'i," Honolulu Advertiser, January 11, 2005,

Wailua project because it would "reduce the flow of Wailua Falls and might endanger native fishes."[90] Like any significant development, hydropower projects are likely to be opposed by at least some.

Figure 8-7. Wailua Falls.

8.4.4 Waimea Mauka

The Waimea Mauka plant in the southwestern portion of the island could receive an upgrade from 1.0 MW to 3.9 MW according to the 1981 Corp study.[91] It was listed as a project of "medium potential". The only Kauai project with "high" potential, the Kaumakani hydropower plant, has already been upgraded. No other details were available on this concept. It is likely that additional capacity is based on utilizing the existing Waiahulu Intake and Waimea Mauka powerplant and converting portions of the

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[89] Himalayan Academy website, Daily Chronicle for August 25, 2004, http://www.himalayanacademy.com/taka/past/2004/August/August_25_2004/

[90] Environment Hawaii, Kauai Development Digest, no date, http://www.environment-hawaii.org/ddkauai.htm.

[91] U.S. Army Corps of Engineers, National Hydropower Resources Study, Regional Assessment: Alaska and Hawaii, Volume XXIII, September 1981.

upstream Kekaha Ditch to penstock to generate additional head. A photo of the generator at the existing power plant is shown in Figure 8-11.

Along with the Kokee project below, the lands draining this project are under the influence of the State Department of Agriculture under the auspices of the Agribusiness Development Corporation (ADC). ADC is also the current project owner. The ADC was formed in 1994 to facilitate and provide direction for the transition of Hawaii's agriculture industry from a dominance of sugar and pineapple to one composed of a diversity of different crops. One of its main objectives is to facilitate in the orderly transition of existing agribusiness resources of land, water and infrastructure as they become available.[92] Another influence on this and the Kokee project may come from one of the last remaining plantation holders, Gay & Robinson, who control 51,000 acres in the area from their headquarters in Makaweli. Gay & Robinson is interested in renewable energy including hydropower to the extent that it creates a positive financial opportunity.

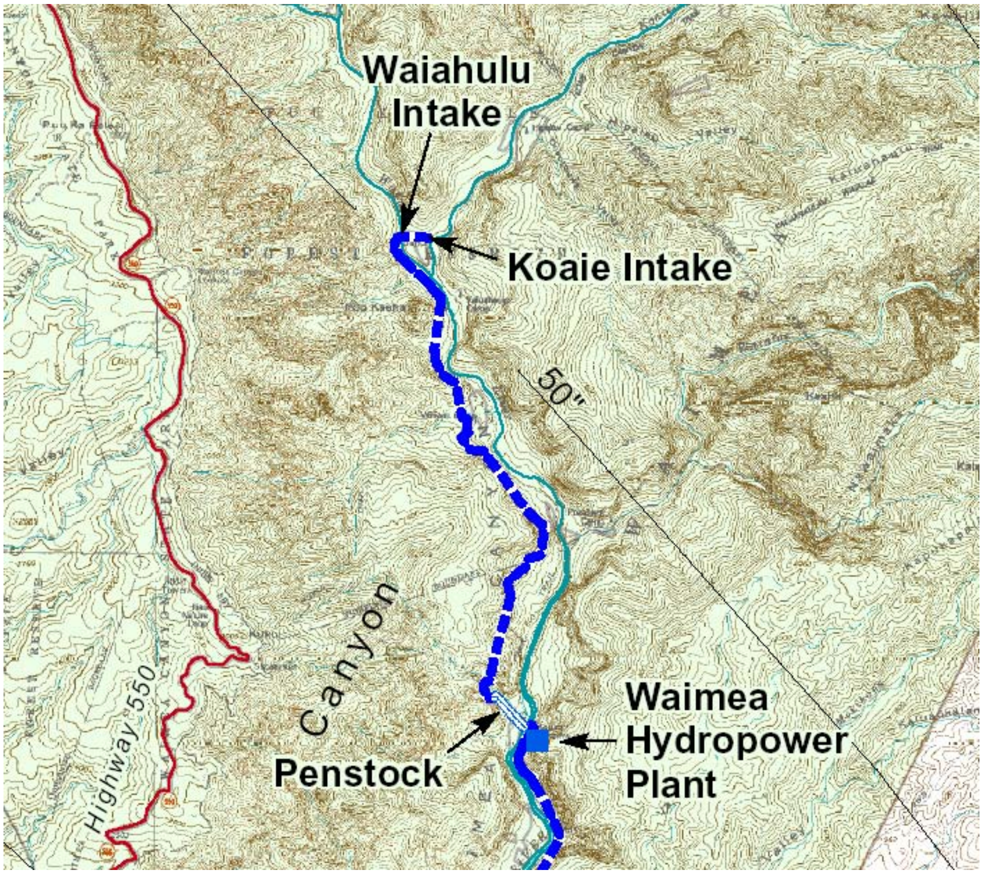

Figure 8-8. Waimea Mauka Hydropower Plant Vicinity (source: Hawaii DOA).

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[92] http://www.hawaiiag.org/hdoa/adc.htm

8.4.5 Kokee

A project which utilizes the developed irrigation systems on the west bank of Waimea Canyon has been envisioned for many decades. A 1964 plan for a large 10 MW storage project never materialized. Later variations in the project included a series of three hydropower plants using existing reservoirs and ditch alignment.[93] The third plant was located on Mana Ridge and required a new easement for the conveyance. This new easement could result in environmental obstacles for realization.

The two-step system recently outlined by the Bureau of Reclamation relies on historical flows along existing ditches and rights-of-way.[94] A 2.97 MW powerhouse at Kitano reservoir would be fed from Puu Lua Reservoir. A second 4.08 MW powerhouse along the Waimea River would take advantage of the steep west canyon wall of this scenic area. The total plant capacity is 7.0 MW exclusive of two small irrigation return turbines which would recapture unused irrigation water. This scheme was selected for consideration because it utilizes existing easements and allows for flexible irrigation flows.

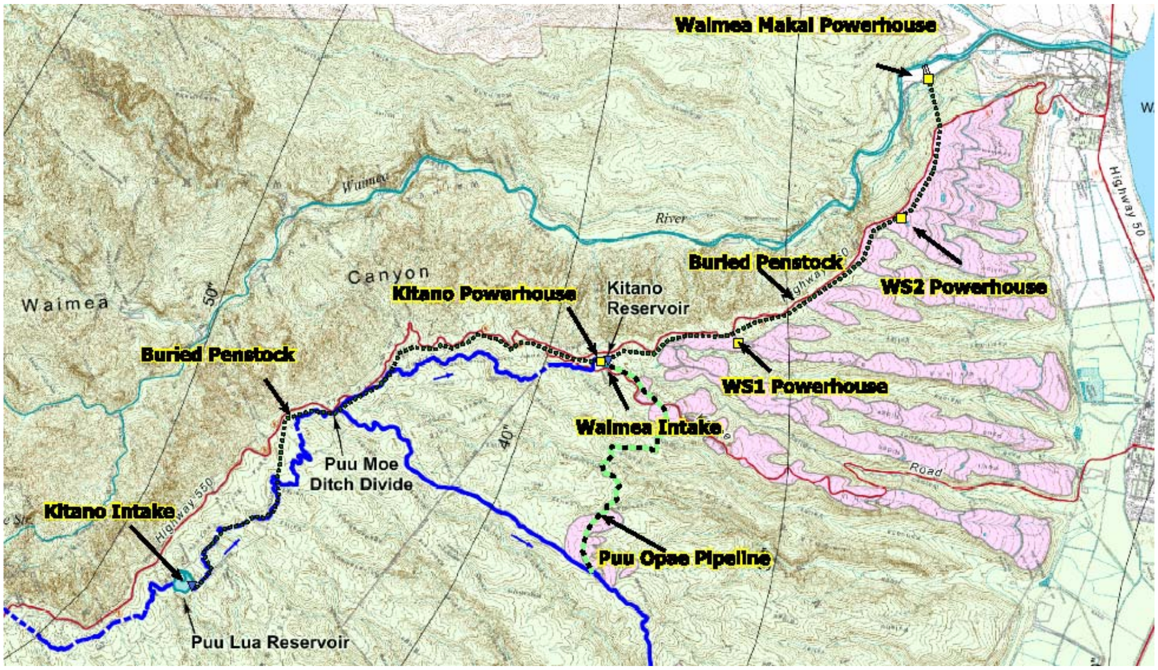

Figure 8-9. Kokee Project Vicinity (source: U.S.B.R. 2004).

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[93] State of Hawaii Department of Land and Natural Resources, Puu Lua-Kokee Hydropower Project: Environmental Impact Statement (Report R70), April 1984.

[94] U.S. Bureau of Reclamation, Lower Colorado Region, "Preliminary Assessment of Small Hydropower Potential on East Kauai Water Users Cooperative Lands and Other Kauai Agricultural Water Delivery Systems," prepared by Ottawa Engineering Ltd., November 2004.

Two Hawaiian Home Lands are apparently located in the vicinity of the project area. Development of the project would thus require consultation.

Costs for the two plants were estimated by the Bureau using RETScreen, renewable energy estimation software developed by the Canadian Department of Natural Resources.

8.5 Power and Energy Production

8.5.1 Plant Performance

There are a variety of methods to estimate performance of proposed hydro projects. One useful method of estimating plant performance is to review generation records for the island's seven existing hydropower plants. However, because these plants were largely in private hands until recently, these records may be difficult to obtain. Power generation records for the existing seven hydropower facilities were not available for review for this study.

A second method of estimating performance is to convert inflow hydrographs into generation based on assumed hydraulic and mechanical efficiencies. Hydrographs can be turned into flow duration curves which plot flow on one axis and frequency of exceedence on the other axis. The flow duration curves for Wainiha and Upper Lihue are available from reports, but not for the other three projects. Nevertheless, the basic data used to develop the flow duration curves was not included in these reports.

The Wailua, Upper Lihue and Kokee plants involve a complex series of diversions, many of which have gaging stations that have been abandoned. Only the Wainiha and Waimea Mauka projects have hydrographs that can be scaled to develop a meaningful powerhouse flow duration curve. Unfortunately, the exact configuration of the proposed Waimea Mauka plant is unknown. For the Wainiha plant, the flow duration curve was developed based stream flow data from 1952 through 2003 (Figure 8-10). An adjustment was not made from the gaging station to the proposed diversion site upstream, but this is only expected to result in a reduction of flows on the order of 10 percent.

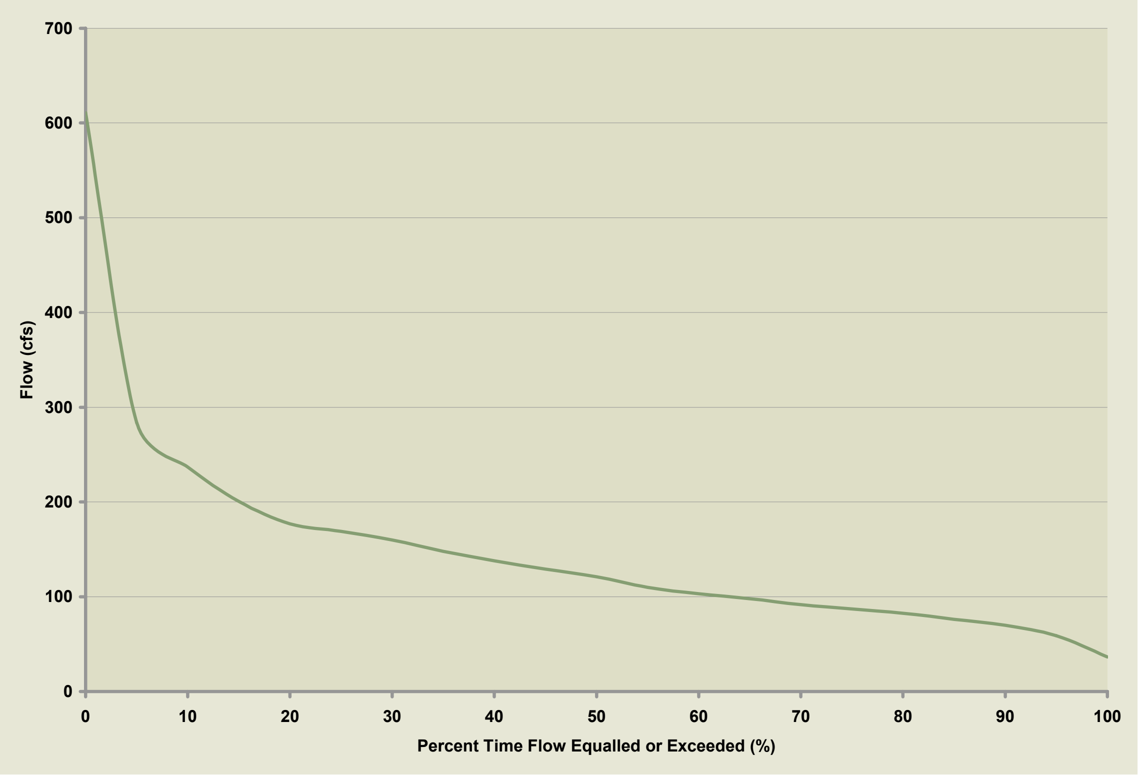

Figure 8-10. Wainiha River Flow Duration Curve, 1952-2003 (Source: USGS).

The additional data since the 1983 EIS does not change the basic shape of the curve, but probably lowers it slightly due to several dry years in the last twenty years.

A RETScreen analysis was used to roughly evaluate the sizing and estimated energy production for the proposed Wainiha Powerplant. A net head of 357 feet was used from the EIS. The calculated turbine and assumed generator efficiencies were 90 percent and 98 percent, respectively. A two-week annual downtime for maintenance was also assumed.

The plant capacity was calculated as 3.9 MW, which matches the 4.0 MW turbine capacity proposed. The annual generation was calculated as 16.9 GWh, which is about 23 percent less than the EIS figure of 22 GWh. The capacity factor calculates at 89 percent, which is in the upper range of the typical 40 percent to 95 percent for small hydroelectric projects. Further studies as recommended in Section 8.8 would be needed to verify these figures.

8.5.2 Operating Profile

Hydro is an intermittent resource and output will vary with rainfall as described previously.

8.6 Cost of Energy

This section presents information to calculate the generation cost of hydro projects including capital cost, O&M cost, and a discussion of applicable incentives. The capital and O&M cost estimates for each of the six projects is shown in Table 8-2. A description of how these values were determined or calculated is below.

Table 8-2. Capital and O&M Costs (2005$) for Selected Hydro Projects.

No.	Project Name	Incremental kW	Incremental GWh/yr	Capital Costs		O&M Costs	
				$M	$/kW	$k/yr	$/kW-yr
1	Wainiha	4,000	22.5	18.0	4,496	270	67.46
2	Upper Lihue	300	1.8	2.2	7,248	30.5	101.82
3	Wailua	6,600	16.4	13.5	2,044	205	31.09
4	Waimea Mauka	2,900	3.9	3.5	1,213	80	27.65
5A	Puu Lua-Kitano	2,970	15.8	17.6	5,933	266	89.64
5B	Kitano-Waimea	4,078	17.1	16.1	3,955	251	61.62

8.6.1 Capital Costs

A nationwide database of hydropower construction cost information per kW of capacity is available from the DOE.[95] In 2003, the nationwide average to develop a hydropower project ranged from about $500-6,000/kW, with a median about $2,700/kW for an undeveloped site, and $700/kW for upgrade projects at sites with existing generation. As would be expected, specific costs decrease with plant size and previous development of the site. Most of the selected projects fit within this range.

Like wind and solar, capital costs for hydropower projects make up most of the overall costs since the "fuel" is "free" once the required infrastructure is in place. For hydropower projects, much of the cost is often off-site from the power plant in the diversion structures, penstock, and their associated access roads. The variability in project site requirements leads to broad ranges of potential costs. For this reason, it is difficult to develop generic estimates of project costs without detailed site studies, and past detailed estimates, despite their age, are preferred.

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[95] Idaho National Engineering and Environmental Laboratory, "Estimation of Economic Parameters of U.S. Hydropower Resources," June 2003.

The Wailua project, and to a lesser extent the Upper Lihue project, are the only projects with line-item construction cost estimates that closely reflect the selected project. Total project cost is all that was available for the Wainiha, Waimea Mauka, and Kokee projects. It is assumed, but could not be verified, that all these lumped costs include engineering and construction administration as well as any required transmission upgrades. Costs were updated from the time of the initial project reports to November 2004 based on the Engineering News Record Construction Cost Index.[96]

8.6.2 Operating and Maintenance (O&M) Costs

Project O&M costs are estimated based on percent of construction cost and staff allocation. The Corps has used 0.5 percent of the construction cost for annual O&M.[97] However, since these plants are small, and two projects are upgrades, this cost was assumed to be 1 percent. O&M costs are expected to be higher for upgrade plants because, though some of the equipment would be new, the diversion and conveyance structures may still require a greater level of maintenance than a new project. One tenth of one percent (0.1 percent) is assumed to be contributable to insurance.

The O&M cost assumes automated power plants with remote monitoring via radio telemetry. Although full-time, on-site personnel are not typically required at these plants, staff will be needed for monitoring, routine site visits, troubleshooting, and annual maintenance. It is assumed that one full staff would be assigned for each of the three new projects (Wainiha, Wailua and Kokee), and that one-half staff unit be added for Waimea Mauka. No additional effort was believed to be needed for the Upper Lihue plant based on the small increase in capacity. Each staff unit was estimated at $90,000 per year including salary and benefits. This addition should give a conservative estimate for annual O&M costs.

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[96] http://enr.construction.com/features/coneco/subs/constIndexHist.asp.
[97] U.S. Army Corps of Engineers, Honolulu District, Summary Report for Hydroelectric Power, October 1978, p. C-9.

Figure 8-11. Waimea Mauka Powerhouse Generator Maintenance (Source: Hawaii Business Magazine, Nov. 2003).

8.6.3 Applicable Incentives

In 2002, State Representative Mina Morita submitted a bill to provide a tax credit of 20 percent for hydroelectric systems erected and placed in service between 2003 and 2010. This bill never passed. The bill which did pass included tax credits only for solar and wind energy. This exclusion, however, apparently was due to State budget limitations rather than a preference for a particular renewable energy technology.[98]

There are several federal incentives available for the development of hydroelectric generation facilities. The federal production tax credit provides a $9/MWh incentive for five years following the initial commercial operation date of the facility, however the facility must be owned by a taxable entity to claim this credit. The hydroelectric facility must also be located in an irrigation system and not use any new dams or impoundments. The incentive would be available for the Upper Lihue, Waimea Mauka, Puu Lua-Kitano, and Kitano-Waimea projects. This incentive is included in the life-cycle cost analysis for the developer owned scenario. Various federal grants and low interest loan programs may also be applicable to these projects; however, the exact impact of these programs is uncertain and not quantified at this time. Therefore, no incentives are assumed in the life-cycle cost analysis for the KIUC ownership scenario.

8.6.4 Life-cycle Economics

The life-cycle cost of providing power from each of the proposed hydroelectric projects was evaluated by calculating the levelized cost. The hydro project performance

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[98] Personal electronic mail correspondence from Rep. Mina Morita, November 16, 2004.

and economic assumptions as well as the results of the life-cycle cost analysis are presented in Table 8-3. A discussion of the modeling approach and detailed financial assumptions are provided in Section 5. Figure 8-12 shows an example life-cycle cost calculation for the Waimea Mauka project.

Table 8-3. Hydro Life-Cycle Economic Assumptions ($2005).

	Unit	Wainiha	Upper Lihue	Wailua	Waimea Mauka	Puu Lua-Kitano	Kitano-Waimea
Capacity	MW	4	0.3	6.6	2.9	2.97	4.078
Capital Cost	$/kW	4,496	7,248	2,044	1,213	5,933	3,955
First Year Fixed O&M	$/kW-yr	67.5	101.8	31.1	27.7	89.6	61.6
First Year Variable O&M	$/MWh	N/A	N/A	N/A	N/A	N/A	N/A
First Year Fuel Cost	$/MBtu	N/A	N/A	N/A	N/A	N/A	N/A
Net Plant Heat Rate	Btu/kWh	N/A	N/A	N/A	N/A	N/A	N/A
Capacity Factor	percent	64%	69%	28%	15%	61%	48%
KIUC Levelized Cost	2009$/ MWh	58.4	86.1	60.4	79.1	81.8	69.9
KIUC Premium	2009$/ MWh	(116.3)	(88.6)	(114.4)	(95.7)	(93.0)	(104.8)
Developer Levelized Cost	2009$/ MWh	123.9	181.5	127.6	146.0	169.2	143.0
Developer Premium	2009$/ MWh	(50.9)	6.8	(47.2)	(28.7)	(5.6)	(31.8)

The levelized cost of generating power from the six projects ranged from $58/MWh for Wainiha to $86/MWh for Upper Lihue assuming KIUC ownership. The extended project life assumption for hydro (50 years) gives hydro a slight competitive advantage over the other resources. However, this assumption is justified based on the long record of successful operation of Kauai's existing hydro plants. Compared to KIUC's forecasted avoided energy costs, the levelized cost premiums ranged from ($116)/MWh to ($89)/MWh. The negative premium indicates that developing these resources is less expensive than the forecasts of KIUC's avoided costs. The best project appears to be the Wainiha project, which had undergone extensive development in the 1980s before being halted due to low power prices.

The levelized cost of power with developer ownership was also calculated. The levelized cost premium was still lower than the avoided cost forecasts, but not as low as with KIUC financing. The levelized cost of generating power with developer ownership was consistently higher than the cost with KIUC ownership, despite the advantage of the PTC. This occurs because of the large difference in financing cost between the developer and KIUC. It is noted that more than the other technologies, KIUC ownership of hydro projects many not be feasible in all situations. KIUC will need to work closely with other parties to ensure the most appropriate arrangement.

Mauka

Hydro

Plant Input Data		Economic Input Data	Rate	Escalation
Capital Cost ($1,000)	3,959	First Year Fixed O&M ($1,000)	90.25	3.0%
Total Net Capacity (MW)	2.90	First Year Variable O&M ($1,000)	0.00	3.0%
Capacity Factor	15%	Fuel Rate ($/MWh)	0.00	3.0%
Full Load Heat Rate, Btu/kWh (HHV)	-			
Debt Term	25			
Project Life	50			
		Present Worth Discount Rate	5.0%	
Hours per Year	8,760	Levelized Fixed Charge Rate	5.12%	

Year	Annual Capital Cost ($1,000)	Fixed O&M ($1,000)	Variable O&M ($1,000)	Fuel Rate ($/MBtu)	Fuel Cost ($1,000)	Total Cost ($1,000)	PW Total Cost ($1,000)	Busbar Cost ($/MWh)	PW Cost ($/MWh)	Avoided Capacity Cost ($/kW)	Avoided Energy Cost ($/MWh)
2009	203	90	-	-	-	293	279	74.93	71.36	0.00	111.89
2010	203	93	-	-	-	296	268	75.62	68.59	0.00	121.46
2011	203	96	-	-	-	299	258	76.34	65.94	0.00	131.10
2012	203	99	-	-	-	302	248	77.07	63.41	0.00	133.40
2013	203	102	-	-	-	304	239	77.83	60.98	0.00	139.93
2014	203	105	-	-	-	308	229	78.61	58.66	160.34	146.48
2015	203	108	-	-	-	311	221	79.41	56.43	162.00	155.09
2016	203	111	-	-	-	314	212	80.24	54.31	160.15	159.54
2017	203	114	-	-	-	317	204	81.09	52.27	192.08	155.25
2018	203	118	-	-	-	321	197	81.96	50.32	192.80	164.57
2019	203	121	-	-	-	324	190	82.87	48.45	192.35	168.47
2020	203	125	-	-	-	328	183	83.80	46.66	183.14	166.80
2021	203	129	-	-	-	332	176	84.75	44.95	203.74	163.22
2022	203	133	-	-	-	335	169	85.74	43.30	200.11	168.86
2023	203	137	-	-	-	339	163	86.76	41.73	196.32	159.73
2024	203	141	-	-	-	344	157	87.80	40.22	214.88	164.41
2025	203	145	-	-	-	348	152	88.88	38.78	202.03	166.83
2026	203	149	-	-	-	352	146	89.99	37.39	206.07	170.16
2027	203	154	-	-	-	357	141	91.14	36.07	210.19	173.57
2028	203	158	-	-	-	361	136	92.31	34.79	214.40	177.04
2029	203	163	-	-	-	366	131	93.53	33.57	218.68	180.58
2030	203	168	-	-	-	371	127	94.78	32.40	223.06	184.19
2031	203	173	-	-	-	376	122	96.07	31.28	227.52	187.87
2032	203	178	-	-	-	381	118	97.39	30.20	232.07	191.63
2033	203	183	-	-	-	386	114	98.76	29.16	236.71	195.46
2034	-	189	-	-	-	189	53	48.30	13.58	241.44	199.37
2035	-	195	-	-	-	195	52	49.75	13.33	246.27	203.36
2036	-	200	-	-	-	200	51	51.24	13.07	251.20	207.43
2037	-	206	-	-	-	206	50	52.78	12.82	256.22	211.58
2038	-	213	-	-	-	213	49	54.36	12.58	261.35	215.81
2039	-	219	-	-	-	219	48	55.99	12.34	266.57	220.12
2040	-	226	-	-	-	226	47	57.67	12.10	271.91	224.53
2041	-	232	-	-	-	232	46	59.40	11.87	277.34	229.02
2042	-	239	-	-	-	239	46	61.19	11.65	282.89	233.60
2043	-	247	-	-	-	247	45	63.02	11.43	288.55	238.27
2044	-	254	-	-	-	254	44	64.91	11.21	294.32	243.03
2045	-	262	-	-	-	262	43	66.86	10.99	300.21	247.90
2046	-	269	-	-	-	269	42	68.86	10.78	306.21	252.85
2047	-	277	-	-	-	277	41	70.93	10.58	312.33	257.91
2048	-	286	-	-	-	286	41	73.06	10.38	318.58	263.07
2049	-	294	-	-	-	294	40	75.25	10.18	324.95	268.33
2050	-	303	-	-	-	303	39	77.51	9.99	331.45	273.70
2051	-	312	-	-	-	312	38	79.83	9.80	338.08	279.17
2052	-	322	-	-	-	322	38	82.23	9.61	344.84	284.75
2053	-	331	-	-	-	331	37	84.69	9.43	351.74	290.45
2054	-	341	-	-	-	341	36	87.24	9.25	358.77	296.26
2055	-	352	-	-	-	352	35	89.85	9.07	365.95	302.18
2056	-	362	-	-	-	362	35	92.55	8.90	373.27	308.23
2057	-	373	-	-	-	373	34	95.32	8.73	380.73	314.39
2058	-	384	-	-	-	384	33	98.18	8.56	388.35	320.68

Levelized Bus-bar Cost, $/MWh	**79.07**
Net Levelized Cost ($1,000)	**309.33**
Levelized Avoided Capacity Cost, $/MWh	**-**
Levelized Avoided Energy Cost, $/MWh	**174.74**
Levelized Cost Premium, $/MWh	**(95.67)**

Figure 8-12. Life-cycle Cost for Waimea Mauka Hydro Project.

8.7 Advantages and Disadvantages of Technology

8.7.1 Fit to KIUC Needs

Like wind and solar, hydro is a gift from the earth. The fuel is "free". The disadvantage is that the earth can be fickle and power production is dependent on the consistency of weather from season to season and year to year. Hydro projects with the exception of pumped storage using sea water, are susceptible to drought. This was evident to Kauai hydropower producers during the most recent drought from 2000 to 2002. A total of six years of drought have been experienced on Kauai in the last 100 years.[99] For this reason the variability in hydropower output is large, even compared with other renewable resources.

As an as-available resource, hydro matches the current energy priorities of KIUC, that is, energy and not capacity.

The hydro projects identified in this report are all relatively small and could be easily integrated into the KIUC energy mix. The Upper Lihue upgrade project is an ideal project in terms of compatibility with KIUC needs. As it is an existing site, the necessary infrastructure (roads, T&D) is already in place to accommodate the increased generation. Further, KIUC already owns the plant, and the new turbine installation would be relatively easy and quick.

8.7.2 Environmental Impact

Hydropower's impacts on the environment and, correspondingly, its ability to be cost-effective and licensable are a function of the technology used. In general, project types in order of decreasing difficulty due to cost, environmental and permitting constraints are:

- Storage (new), including pumped
- Run-of-river or (trans-basin) diversion
- Run-of-ditch or storage (existing)
- Plant enlargement
- Equipment upgrade (new or refurbished turbine/generator)

Storage hydro resulting in the damming of rivers can result in significant environmental impacts including interference with fish migration and flooding of sensitive archeological, agricultural, natural or developable lands. Off-stream storage and run-of-river projects mitigate some of these impacts of flooding. On the positive

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[99] State of Hawaii Commission on Water Resource Management, http://www.hawaii.gov/dlnr/cwrm/drought/history.htm

side, storage can provide both valuable flood control as well as recreation areas. Nevertheless, the sources reviewed make it clear that new storage projects are unlikely due to environmental impacts. Hydropower projects which utilize existing storage have the advantage of these impacts already considered in the island's ecology. This is also true for run-of-ditch projects where historical diversions are already captured for power production. Least obtrusive of all are upgrades to existing facilities, either by enlarging the plant's capacity by adding units or simply updating or upgrading equipment to increase flexibility and efficiency. The latter are least subject to environmental concerns since work is completed within existing structures. These projects are sometimes referred to as incremental hydro because they do not alter stream flows.

Unlike wind and solar energy, hydropower does "consume" a competitively pursued agricultural and scenic resource: water. Nevertheless, agriculture, scenic streams and waterfalls can be maintained in part by providing minimum instream flows as laid out in the Hawaii's State Water Code legislated first in 1987. The Code aims at protecting the natural, recreational, scenic, navigation, water quality, irrigation *and hydropower* resources for waters of the State.[100] According to State Representative Mina Morita, to date standards have not yet been set for individual streams in Hawaii.[101] This adds to the uncertainty of calculating benefits of hydropower projects which rely on these base flows for both revenue and reliability.

Permits

Unlike many other renewable energy systems, hydropower often impacts a larger area and is closely tied to the use of larger surface waters which compete with other uses. This typically translates to a larger number of permits. Permits which may not apply to other energy sources, but that will or may be required for new hydropower projects on Kauai are:

- Corps 404 Permit, involves Section 7 Consultation with U.S. Fish & Wildlife and other federal agencies
- State Board of Land and Natural Resources, Stream Channel Alteration, Stream Diversion, and Conservation District Use Permits

Hydropower projects that are upgraded will generally require a smaller number of permits.

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[100] State Water Code, Section 174C-3.

[101] Personal telephone conversation with Representative Mina Morita, November 16, 2004.

Sensitive Species

Hawaii has the highest number of federally-listed endangered and threatened species in the United States. There are 317 threatened and endangered species in the state, of which 44 are animals and 273 are plants.[102] Plant and animal species that rely on perennial or intermittent streams are most impacted by hydropower projects which derive their energy source from streams. Many parts of Kauai have been designated critical habitat meaning that they are considered essential for the conservation of a threatened or endangered species. Projects proposed within these habitat areas require special consideration when a federal permit, such as a FERC license or Corps 404 permit, are involved.

In general, all water projects, including hydropower, will involve careful assessment of affected animal and plant species. Some pertinent examples for Kauai are discussed below.

Birds

Many of the animals listed as endangered for Hawaii are birds. Some endangered species are specific to Kauai including those in the thrush and honeycreeper families. These native birds are especially found in the higher elevation of the islands where hydropower development is more likely. One report on the Large Kauai Thrush lists the construction for an un-named dam for hydropower and irrigation as a threat to this bird.[103]

Goby

One species of needed study for hydropower projects is the native goby (*'o'opu*) fish. Five species of native goby occur in streams in the Hawaiian Islands.[104] Although the goby are not listed as endangered, one species was listed as a Candidate species on the Federal Register, and was considered 'threatened' by the American Fisheries Society (AFS). Two other species were considered to be species of special concern by the AFS.

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[102] U.S. Fish and Wildlife Service, http://ecos.fws.gov/tess_public/TESSWebpageUsaLists?state=HI

[103] Virginia Tech Conservation Management Institute, http://fwie.fw.vt.edu/WWW/esis/lists/e101023.htm

[104] Hawaii Biological Survey website, http://hbs.bishopmuseum.org/.

Figure 8-13. Native Goby ('O'opu) (Source: Hawaii Biological Survey).

'O'opu have an amphidromous life cycle; they migrate to and from the sea but do not use the ocean for reproduction. *'O'opu* spend their entire adult lives in freshwater streams. They reproduce in the stream, laying their eggs on the upper surfaces of rocks and hatch within 48 hours. Larvae then drift out to the ocean and spend up to 160 days in a planktonic state. Returning post-larval *'o'opu* may ascend randomly to streams and at times in great numbers. Some species are capable of climbing waterfalls and areas of rapids as high as 1000 feet. One species is known to migrate downstream to spawn on riffles located just upstream of the ocean. Downstream spawning runs are believed to be triggered by the first large rainstorm in the fall. However, postlarvae have been found throughout the year, indicating that some degree of spawning occurs throughout the year.

A major ecological requirement for *'o'opu* is the need to pass through a stream mouth at two times during the individual's life. The most important factor for the existence of endemic *'o'opu* in streams is that access to and from the ocean is maintained. Stream channelization and diversions can significantly impact native fish populations within a stream.

Newcomb's Snail

Newcomb's Snail is a federally and state-listed endangered species known to inhabit streams on Kauai. A recent federal rule established critical habitat area for this snail. [105] Significantly, this designation does not conflict with the two proposed run-of-river projects. The Wainiha River was excluded from the Critical Habitat Area for the

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[105] U.S. Fish and Wildlife Services, "Endangered and Threatened Wildlife and Plants; Designation of Critical Habitat for the Newcomb's Snail; Final Rule, 50 CFR, Part 17, August 20, 2002.

federally and State Endangered Newcomb's Snail. The North Fork Wailua River below Elevation 1100 feet was excluded from the Critical Habitat Area. The public discussion centered around the establishment of the Critical Habitat Area shows that not only environmental, but also development issues, such as hydropower, are addressed to try to maximize benefits for all uses.

Plants

Most of Hawaii's endangered plants occur in the upper dry and wet forests in small isolated areas.[106] The U.S. Fish and Wildlife Service has established Critical Habitat Areas for 95 non-aquatic plant species on the Islands of Kauai and Niihau. The areas expressly exclude both the proposed sites for the Wainiha and Wailua projects.[107]

8.7.3 Socioeconomic Impacts

The socioeconomic impact of hydro varies. Large hydro projects are massive construction efforts that create many long lasting operations and maintenance jobs. The hydro projects considered here are much smaller and have smaller impacts. Long-term job creation is minimal, although there will likely be 20-40 temporary jobs created during the construction of the new sites (18 to 24 months).

8.7.4 Incentives / Barriers

There are a variety of incentives and barriers to hydro project development on Kauai.

Storage projects can provide valuable flood control. Even run-of-river projects remove flow from natural streams allowing for more controlled releases and the potential for damage to bridges and culverts downstream. Recreational opportunities often follow hydropower projects as access is provided to remote areas for fishing and hiking. Even research and scientific exploration can also be enhanced via additional data from stream gages, weather stations, communications systems, etc. normally associated with hydropower development.

Hydropower is generally viewed less favorably on Kauai than other renewable forms of energy. This may be due, in part, to the dependence of the largest business, agriculture and tourism, on reliable water. Hydropower competes to some extent with this water. Previous experience with potential development that did not adequately address these issues may have left a sense of suspicion about hydropower. These

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[106] U.S. Army Corps of Engineers, Honolulu District, Summary Report for Hydroelectric Power, October 1978, p. E-2.
[107] Federal Register, Volume 68, Number 39, Sections 68 and 69, February 27, 2003.

misgivings can only be overcome by environmentally-sensitive projects than leave the door open for agricultural uses.

Hydropower could be seen by others as ancient history since the last new hydropower plant on Kauai, Waimea Mauka, was constructed a half century ago. The last round of proposals in the early 1980's for Wainiha, Wailua and Kokee all proved to be disappointing, which would lead some to believe that hydropower does not have a bright future in Kauai. Nevertheless, these efforts seemed to have failed primarily for economic, rather than environmental or social reasons. Increasing fossil fuel prices and an increasing sense of need for self-sufficiency may tip this balance. As previously stated, hydropower uses both natural and developed sources already available to Kauai which seems to fit the island's philosophy of "use what you got."[108]

Hydro projects, especially run-of-river, can be constructed with a very low profile and can, in fact, be generated underground with little visual impact. This reflects a desire for a "parklike" appearance throughout the island documented in the Kauai General Plan.[109] This is an advantage in a scenic region like Kauai.

This low profile can also be an advantage in areas subjected to tropical storms and hurricanes, where elevated structures associated with wind and solar energy can be exposed to severe loading conditions. No reported damage to hydropower resources has been noted in this study due to the devastating Hurricanes Iniki in 1992 and Iwa in 1982. In fact, it was reported that after Hurricane Iniki, power was first restored on Kauai to the Princeville area thanks to its reliance on Kauai's largest hydropower plant at Wainiha.[110]

Perhaps one of the greatest advantages of hydropower is long life, typically considered to be at least 50 years. Of the seven operating hydro plants on Kauai, all are now over 50 years old, with the Wainiha plant approaching its 100th anniversary. Though equipment must be maintained and occasionally replaced, the very stability of the hydro technology due to its simplicity and high efficiencies means that major upgrades or changes of technology are not needed to continue producing reliable power for many decades.

8.8 Next Steps

To further narrow the selection of potential hydropower projects and fairly compare cost and other factors with other renewable technology, we recommend the following additional sources of information and studies be pursued for projects identified

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[108] Telephone conversation with Laurie Ho, Natural Resource Conservation Service, Lihue, Kauai on November 16, 2004.
[109] County of Kauai Planning Department, Kauai General Plan, November 2000.
[110] Personal telephone conversation with Representative Mina Morita, November 16, 2004.

as promising. This effort would bring potential hydropower projects to a feasibility level of study.

8.8.1 Additional Sources

The following sources may prove helpful for a further evaluation of the identified projects:

- Source data for 1981 Corps of Engineers National Hydropower Resources Study Regional Assessment for Alaska and Hawaii.
- State of Hawaii Department of Land and Natural Resources reports on Waialeale and Kokee Hydroelectric Projects
- Additional sources of information for used Department of Energy study assessments
- Power generation records from the Wainiha, Upper Lihue, and Waimea Mauka hydropower plants
- Conceptual design reports, plans, data and calculations prepared by McBryde Sugar Company in the 1980's for Wainiha
- Conceptual design reports, plans, data and calculations available at Gay & Robinson for projects at Waimea Mauka Powerhouse and in the Kokee region.
- Planning documents prepared by Northwest Power for the Wailua Hydroelectric Project.

8.8.2 Feasibility Study

To bring specific hydropower projects to a feasibility level of effort, the following activities are recommended for each selected project:

- Complete one-day site visit
- Perform site specific hydrological studies to develop a powerhouse hydrographs
- Explore site specific constraints with government resource and planning agencies and affected or interested businesses, groups and individuals.
- Develop conceptual design plan from which quantities for construction could be estimated and costed.

9.0 Wind

The wind regime throughout Kauai is varied with respect to its strength and accessibility. This section provides an overview of resources on the island and identifies eleven potential project areas. Out of these, seven potential sites were labeled as medium or high priority, and are characterized here.

9.1 Basis for Assessment

The single most critical factor of wind energy development is the wind resource. Using a wind resource map for Kauai developed by the Hawaii Wind Working Group and validated by the U.S. Department of Energy, Black & Veatch and KIUC identified 11 potential locations for wind energy project development. Black & Veatch has further assessed each site based on overall wind resource and associated energy production potential, the feasibility of construction at each site, the site's proximity to appropriate transmission lines, and other factors. Based on these criteria, Black & Veatch classified each site as having a "low", "moderate" or "high" potential to support a wind energy project. Evaluation of each site is provided in Section 9.3.

In addition, a limited amount of anemometer data was available for analysis. This information was assessed for applicability to the sites and used when appropriate.

9.2 Assessment of Contributing Resource

In general, the wind resource on Kauai is sufficient such that it should not limit the amount of wind energy which may be productively developed on the island (refer to Section 3.8 for a more complete discussion). The most likely limit to wind power development will be the amount of wind-generated electricity that can be productively integrated in to the KIUC system. Black & Veatch was directed by KIUC to investigate wind energy options up to 7 MW in nameplate rating, which is approximately 10 percent of the island's peak load. Larger projects may be incorporated in the future once operational experience at this level of penetration proves such expansions practical.

Wind is created primarily by global temperature fluctuations and thermal interactions between land, sea, and air. Wind energy systems convert the power of moving air into electricity. Aerodynamic forces act on the rotor to convert the linear motion of the wind stream into the rotational motion needed to turn an electrical generator. The available power in the kinetic energy of the wind is given by the relation:

$$P = \tfrac{1}{2}\rho A V^3$$

where ρ is the air density, A is the rotor area intercepting the wind, and V is the upstream wind velocity. Of these, wind velocity is most important. The cubic dependence of wind power on wind speed implies that energy output, and consequently the economics of a wind turbine installation, is highly sensitive to wind speed. A 10 percent change in velocity results in about 30 percent change in available energy; thus wind speed is one of the most critical factors in determining wind energy generation. Wind power density is expressed in Watts per meter squared (W/m^2) and incorporates the combined effects of the time variant wind speed and the dependence of wind power on both air density and cube of wind speed. The figures in this report show wind power density categorized by wind power class from 0-7, as discussed in Section 3.8 previously.

Average wind speeds vary significantly geographically. Local factors such as high altitude, unobstructed terrain, lofty airflow height, and natural wind tunneling features cause some areas to have inherently higher wind speeds than others. Wind speed is affected by the height above ground level (AGL). Ideally, wind resources assessments are performed at the hub height of the candidate wind turbine (40 to 80 m); however, if measurements at the actual hub height (Z) are not available, wind speed (v) can be extrapolated from other measurement heights. The most common method is the following relation, known as the one-seventh power law:

$$\frac{v_2}{v_1} = \left(\frac{Z_2}{Z_1}\right)^{1/7} \quad or \quad \frac{P_2}{P_1} = \left(\frac{Z_2}{Z_1}\right)^{3/7}$$

For example, based on the one-seventh power law, wind speed and wind power (P) at 30 m above the ground are respectively 17 and 60 percent greater than at 10 m. Although a convenient approximation, the one-seventh power law has no theoretical basis. A custom power law can be applied to a specific site data by measuring wind speed at two or more different heights on the same tower and determining the wind sheer factor (s) for a specific site. Once a sheer factor is known for a site wind speed can be scaled using the following equation:

$$v_2 = v_1 * \left(\frac{Z_2}{Z_1}\right)^S$$

The site-specific nature of the wind energy resource underscores the need for well planned assessments. The one-seventh power law may be inadequate because it is only an approximation and the amount of wind energy available is strongly affected by the local terrain. If the wind sheer factor for a specific site is known, a more accurate power estimate can be made from non hub height data. A thorough study of the wind at a particular site is advisable before installing wind turbines. Collecting data at multiple hub heights and locations allows for the optimum design and placement of individual turbines in large turbine arrays or on complex terrain. In this report, a wind sheer factor was estimated for each site based on the local topography.

The site wind resource is of critical importance to a wind project because it is the fuel for the power plant. Wind generation suffers in notoriety because it is intermittent – subject to the strength and consistency of the wind. Because of this, the best way to ensure a successful project is to collect as much data as possible and make informed decisions at every step of the project development. This data should be compared against historical data for the area for the longest possible time span that data can be obtained.

For the purposes of this study, the wind resource has been evaluated using data acquired in three areas: at the western edge of Hanapepe Bay (Port Allen site), at the southern end of a ridge north of Hanapepe (Hanapepe site), in the foothills of Mount Puu Ehu on Hawaiian Home Lands property (Anahola site). Four other areas; Omao, Kokee, Poipu, and Maha'ulepu, are analyzed to a lesser degree using the validated Kauai wind map. It is assumed that a 7 MW wind project would be developed at each site, with the exception of the Kokee site, where only a 2 MW project development is assumed.

The wind data analyzed in this study was collected by anemometers mounted at 90 feet (27 m) above ground level on towers near the Anahola and Hanapepe sites, as well as an anemometer mounted at 30 feet (9 m) above ground level near Port Allen. The period of time that the analyses cover is one calendar year for each site: 1994 for both Anahola and Hanapepe, and 1997 for Port Allen. These full-year data sets are enough to create preliminary wind models for these three projects sufficient for this study. However, prior to making the large investment for any of these projects, Black & Veatch advises KIUC to install and collect data from taller towers (preferably at the hub height of the proposed turbines) for a period of not less than one year.

In general, wind on Kauai is stronger in the summer than winter, and in the afternoons than in the evening or morning. A figure showing diurnal (hourly) and seasonal wind variations in the Port Allen data (extrapolated to 164 ft, 50 m) is shown in Figure 9-1.

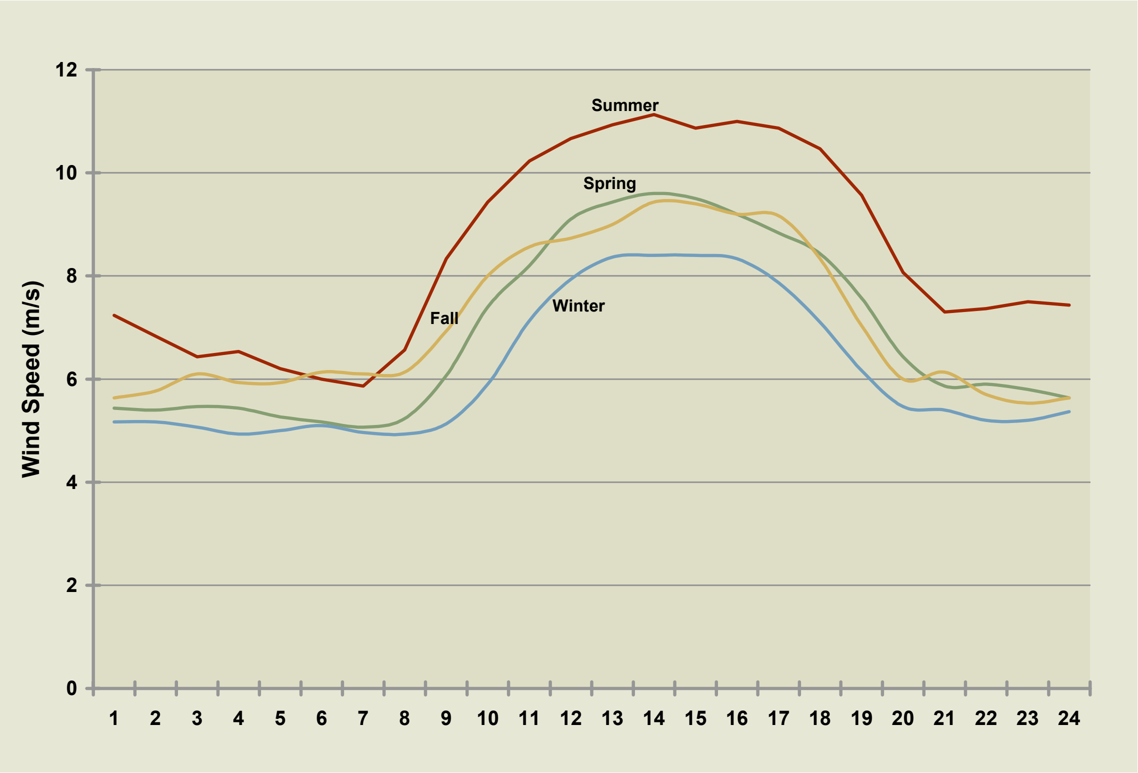

Figure 9-1. Hourly Average Wind Speeds by Season, Port Allen.

9.3 Project Option Screening

Based on a wind resource map for the island, eleven areas were identified by Black & Veatch and KIUC as having some potential for wind energy development. These are shown in Figure 9-2. To evaluate each site, Black & Veatch considered several additional factors that impact a site's feasibility and cost. These factors included:

- Pattern of wind resource (time of day, time of year)
- Proximity of transmission lines
- Land ownership
- Construction accessibility
- Compatibility with existing land uses
- Environmental sensitivity and permitting issues

A brief discussion of each site is provided below. It should be noted that the focus of this report is to identify broad areas that may be generally suitable for wind development. Specific project locations, including possible turbine layouts, have not been identified. A Vestas V47 wind turbine at 50 m hub height was assumed in generating capacity factor estimates. The V47 is a typical turbine of this class.

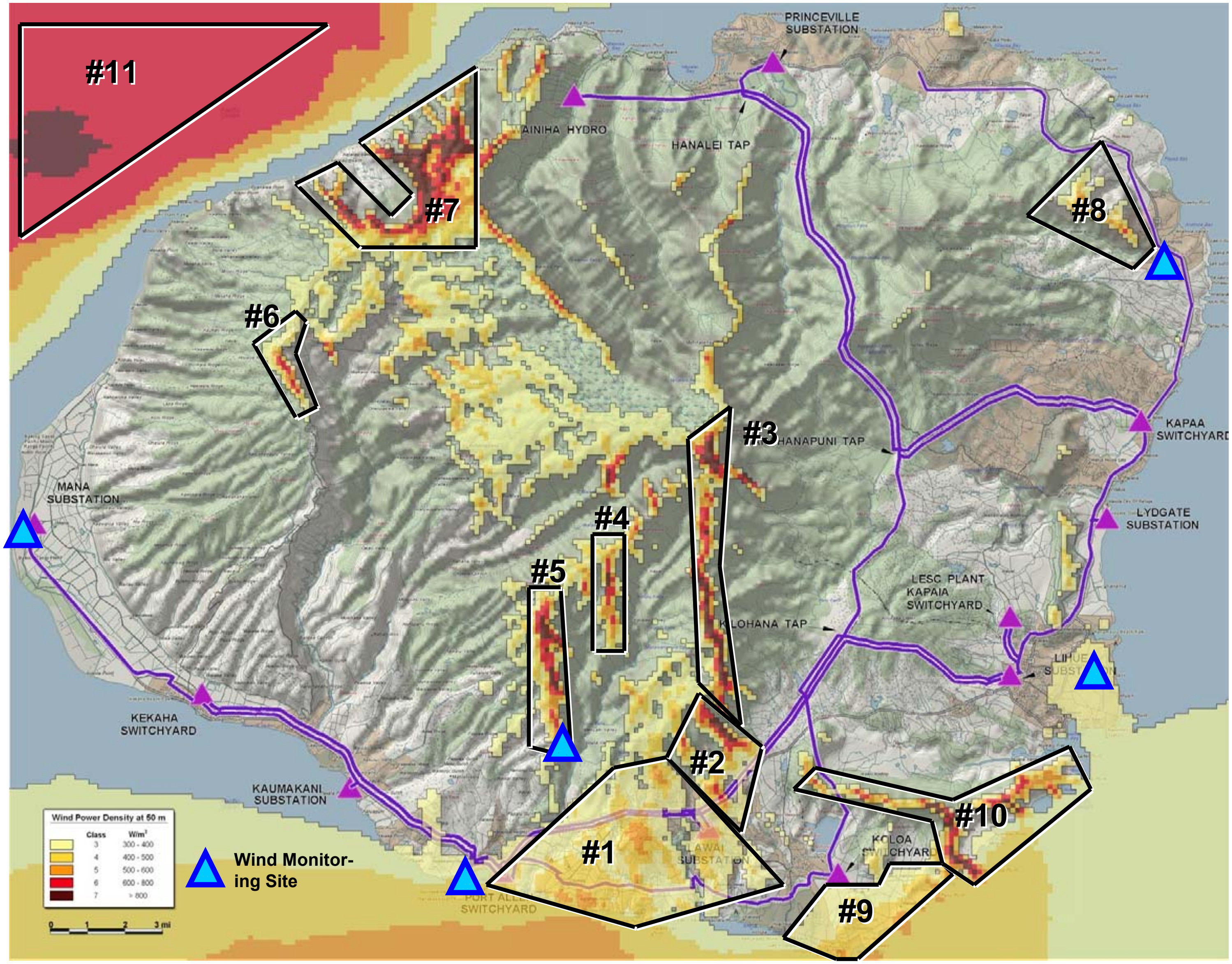

Figure 9-2. Potential Wind Project Sites.

9.3.1 Area #1: Kalaheo

This is a large region of moderate Class 3-5 winds filling the area around Kalaheo from the mountains to the coast. It is an agricultural area deemed likely compatible with wind power, with significant tracks of relatively flat terrain which would lower construction costs. The highest wind resource identified in the wind maps are along the coast and southwest of the town of Kalaheo, both of which are close to KIUC transmission lines.

Black & Veatch estimates the wind resource in this area could yield capacity factors near 35 percent based on analysis of available wind data. The site is not geographically limited to further expansion, so additional project phases could be added. Alexander & Baldwin is the area's largest landowner, and there are other significant private holdings as well. Due to the relatively high wind resource, flat topography, and transmission access, Black & Veatch ranked this site as a "high" priority for further investigation. A photo of the area is shown in Figure 9-3.

Figure 9-3. View from Kalaheo Site Looking South.

9.3.2 Area #2: Omao

A series of low ridges in the foothills north of Lawai make up the Omao area. The ridgeline resource in this area may be difficult to construct, especially sites up the ridges, significantly removed from Highway 50. The best wind sites in the area, according to the wind maps, are along a ridge next to the highway with Class 5 and 6 winds which yield an estimated capacity factor of 34 to 37 percent, and a ridge further north with class 6 and 7 winds which yield an estimated capacity factor of 36 to 40 percent. The nearer ridge is close to major transmission lines. The greater resource of the more distant ridge may justify extending transmission and roads. The near ridge would be appropriate for a 7 MW wind farm, with the possibility of an expansion doubling its capacity in the future. The far ridge has room for approximately 40 MW of installed capacity. Land ownership in this area is mixed and visibility may be an issue due to the proximity of the highway. Due to the strong resource and proximity to roads and transmission, Black & Veatch ranked this site as a "moderate" priority for further investigation. A photo of the area is shown in Figure 9-4.

Figure 9-4. View of Ridge at Omao Site with Transmission.

9.3.3 Area #3: Waialeale South Ridge

This area is a ridge extending up to the peak of Mt. Waialeale. This site is located in a natural area and wind power may not be compatible with this land use. A project in this area would be expensive to construct due to lack of roads and steep terrain. However the ridgeline resource here is excellent, with Class 6 and 7 winds which yield an estimated capacity factor of over 40 percent and theoretical space for over 100 MW of capacity. It may be expensive to extend transmission to this area. Land ownership in this area is mixed. Due to the inaccessibility and untouched nature of the area, Black & Veatch ranked this site as a “low” priority for further investigation.

9.3.4 Site #4: Kuahua

This area is similar to the Waialeale South Ridge area; it is a remote ridge high on Mt. Waialeale with expensive construction and transmission access. The wind resource is slightly less and the access may be slightly better than Waialeale South Ridge. The land is owned by the Robinson family. Due to the inaccessibility, single landowner, and untouched nature of the area, Black & Veatch ranked this site as a “low” priority for further investigation.

9.3.5 Site #5: North of Hanapepe

This area is similar to areas 3 and 4 in that it is a ridgeline on the south slope of Mt. Waialeale with exceptional wind resource. Construction on the ridgeline may be difficult and transmission would have to be extended two or more miles to reach the project. The wind resource is considerable though, according to the wind map, with wind Class 5 to 7. A capacity factor of 36 percent is estimated at the anemometer site based on Black & Veatch analysis of available wind data. Capacity factors in excess of 40 percent are likely further up the ridge. Development could begin at the bottom of the ridge and expansions could potentially extend further up the ridge to a theoretical potential of around 100 MW capacity. Data has been collected at the southern end of the ridge. Due to the difficult access, but abundant wind resource and available data Black & Veatch ranked this site as a “moderate” priority for further investigation.

9.3.6 Site #6: Kokee

There is a pocket of good wind resource straddling Highway 550 west of Waimea Canyon in Puu Ka Pele Forest Reserve. The existing road is promising for allowing construction, but the terrain may still present construction issues. The wind map indicates about 15 to 20 MW potential with Class 5 and 6 winds yielding an estimated capacity factor of 35 to 38 percent. Extending transmission lines to this area may be prohibitive, but existing distribution lines do exist. This site may be well suited for distributed generation up to the capacity of the distribution line (2 MW has been assumed). Visual impact may be a concern due to the site's proximity to the scenic highway, Waimea Canyon, and Kokee State Park. Due to the good resource and accessibility of this area, Black & Veatch ranked this site as a "moderate" priority for further investigation.

9.3.7 Site #7: Kalalau

The high ridgelines around the Kalalau valley have some of the best wind resources on Kauai. However, this area is remote and scenic, and construction access is difficult, if not impossible. It is deep in a natural area and wind power is probably not compatible with this land use. This area may be prohibitively far from transmission and extending lines could be challenging. However, the wind resource here is excellent with Class 6 and 7 winds having an estimated capacity factor in excess of 40 percent and theoretical space for hundreds of megawatts of capacity. The land is owned by the state of Hawaii and is part of the Na Pali Kona Forest Reserve. Due to the inaccessibility and untouched nature of the area, Black & Veatch ranked this site as a "low" priority for further investigation.

9.3.8 Site #8: Anahola

This area is on Mt. Puu Ehu near Anahola. Roads and transmission would likely need to be expanded to develop this site but, the extension would not be prohibitive. Construction on steep terrain may be a concern. The wind map indicates about 25 to 30 MW potential with Class 4, 5 and 6 winds yielding an estimated capacity factor of 34 percent based on Black & Veatch analysis of available wind data. It is understood that there may be local interest and support for a wind project at this site, which can be a big asset for project development. Wind data is available for a location near this site. A small portion of the project site is Hawaiian Home Lands and the remainder is state land (Molona Forest Reserve). Due to the good resource, available data, and potential political support Black & Veatch ranked this site as a "high" priority for further investigation.

9.3.9 Site #9: Poipu

The area around Poipu on the south of the island is similar to the first area, Kalaheo, in that it has low lying, reasonably flat terrain facilitating ease of construction. The area is one of the principal tourist locations on Kauai and is experiencing rapid development. Wind speeds on the wind map are lower than at Kalaheo with mostly class 3 and 4 winds yielding an estimated capacity factor of 30 to 33 percent. The windiest sites, according to the wind map, are along the coast which is further from transmission lines and more intensely developed. Distribution lines extend throughout the area and could be used in a distributed generation scenario. Alternatively, installation of 3 or more miles of new transmission line over flat terrain may be feasible. Land ownership in this area is mixed, with Grove Farm as the largest single land holder. Any wind development would need to be carefully approached to minimize local tourism impact. Due to the accessibility of the site and proximity to loads Black & Veatch ranked this site as a "moderate" priority for further investigation.

9.3.10 Site #10: Maha'ulepu

Maha'ulepu is another area of excellent wind resource. It extends inland from the south east coast and is near the major load centers of Lihue and Kapaa. The inland end of this ridge comes reasonably close to Highway 50 and transmission lines pass through it. Further stages extending coastward could be developed. According to the wind map, a site with approximately 10 MW of potential is available at the western end of this area near Highway 50. This site has class 5 and 6 winds yielding an estimated capacity factor of 34 to 37 percent. An additional 50 to 100 MW of expansion is possible following the ridge eastward, where capacity factors of up to 40 percent could be expected. The area has a high cultural value and other proposed (non-wind) developments have been challenged. It is also very scenic and visible from Highway 50. The ridge is steep and construction could be difficult. Land ownership is split between the A.E. Knudsen, Grove farm, and others. Due to the strong wind resource and proximity to load centers, Black & Veatch ranked this site as a "moderate" priority for further investigation.

9.3.11 Site #11: Offshore

Large areas of ocean to the northwest and southwest of Kauai show excellent wind resource potential on the wind maps with class 6 and 7 winds. However the ocean shelf drops off quickly in both of these areas making them unsuitable for existing commercial offshore technology. Deep water off shore power is not yet a proven technology, so Black & Veatch ranked this site as a "low" priority for further investigation.

9.3.12 Project Area Summary

Table 9-1 shows a summary of the project areas characterized. Excluding the offshore resource, over 600 MW of potential projects have been identified. The two highest priority sites are the area south of Kalaheo (Area #1) and the ridges near Anahola (Area #8). In the remainder of the report, Black & Veatch will focus on characterizing projects in high potential areas. Nearby wind data will be used as a reference. Black &

Veatch will also compare the relative merits of the medium priority sites. Low priority sites will not be reviewed in any further detail.

Table 9-1. Project Option Screening.

Area	Construct-ability	Trans-mission Access	Potential MW	Wind Class	Capacity Factor	Suitable for Dist. Project?	Priority
1: Kalaheo	good	good	100+	4-5	35%	yes	high
2: Omao	fair	good	15-55	5-6	34-40%	yes	moderate
3: Waialeale	bad	bad	100+	6-7	40%+	no	low
4: Kuahua	bad	bad	50	5-7	35-40%	no	low
5: Hanapepe	fair	fair	100+	5-7	36%	no	moderate
6: Kokee	good	fair	15	5-6	35-38%	yes	moderate
7: Kalalau	bad	bad	100+	6-7	40%+	no	low
8: Anahola	fair	fair	25	4-6	34%	yes	high
9: Poipu	good	good	100+	3-5	30-33%	yes	moderate
10: Maha'ulepu	fair	good	10-100	5-6	34-40%	no	moderate
11: Offshore	bad	bad	100+	6	40%+	no	low

9.4 Project Technical Description

This section provides an overview of project scale, turbine selection, and project conceptual design for each moderate and high ranked wind resource area.

9.4.1 Project Scale

There are two different philosophies for wind power development that can be used on the island: a central expandable wind plant, and distributed generation. A central wind plant involves placing all turbines in a single high wind resource area and providing for successive stages of development. This approach provides for construction and wind assessment economies of scale as well as maintenance and dispatch convenience. More detailed wind resource assessment is also feasible at a single site. A central plant concentrates the visual impact and can limit the number of property owners involved. Future additions of wind power at the central plant may be facilitated since community concerns, permitting, transmission issues, and roads have in large part been addressed.

A distributed generation strategy involves placing smaller groups or single turbines in multiple locations. Smaller groups of turbines can potentially use distribution-level utility lines instead of main transmission lines to collect power. Wind turbines spread over a larger geographical area will present a smoother ramp up/down of collective power output easing the compensation dispatch requirements for the utility. Distributed generation can also provide voltage support for remote transmission lines if times of strong wind coincide with times of peak electric uses. Distributed generation also potentially allows for partnership with local energy users. Class 3 wind sites may be attractive if a large power user has an avoided cost equal to the retail rate for power. Such users could include: farming operations, manufacturers, hotels (green marketing), schools (education opportunity), and native communities. Furthermore, several sites with good wind but too small for a full 7 MW may be utilized, including: the point north of Kilauea, the ridgeline north of Hanamaulu, the small peninsula to the south west of Hanapepe and the Port Allen airport, and edges of the eleven described areas above. Potentially, turbine ownership could be mixed allowing power users, developers, and/or investors to own or partially own turbines, reducing the capital burden on KIUC.

Central plant projects for both areas designated high priority (Kalaheo and Anahola) as well as one for Hanapepe will be described in 9.4.3 and 9.5. A more general description for the other moderate priority areas will be included as well as a distributed generation scheme at Kokee.

9.4.2 Turbine Selection

Wind turbines transform the kinetic energy of the wind into mechanical or electrical energy that can be harnessed for practical use. The wind turbine design that is commonly in use today is the horizontal-axis turbine. These turbines are comprised of a gearbox and generator in a nacelle at the top of a large tower (see Figure 9-5). These components receive rotational energy through a rotor to which typically three large blades are attached. Vertical axis wind turbines and other designs are no longer commonly used.

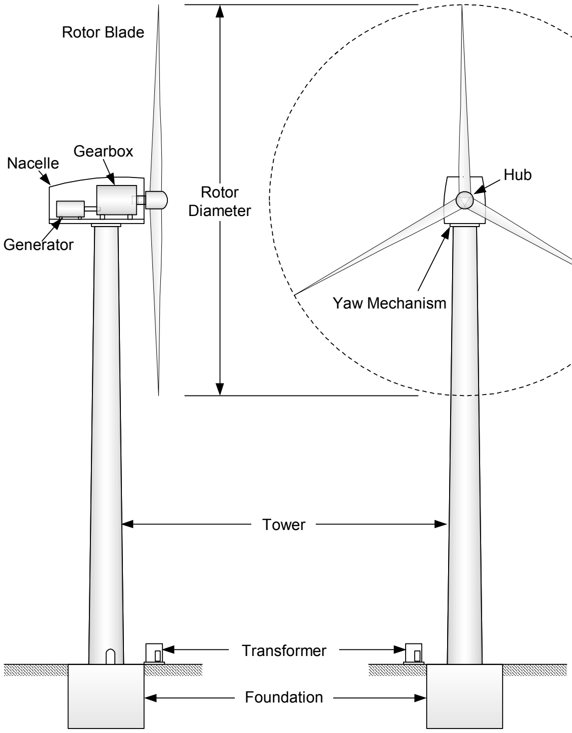

Figure 9-5. Schematic Diagram of a Horizontal Axis Wind Turbine.

The power of a wind turbine is proportional to the swept area of its rotor, and at a typical site, about 500 W/m^2 intercepted by the rotor would be the upper limit of what could be expected from any conventional machine. Machines vary in size from 600-mm (2 ft) rotor diameter, rated at about 50 W, to 104-m (340 ft) rotor diameter, rated at about 3.6 MW. Today, typical wind turbines for commercial utility application range from 600 to 2,000 kW. The general trend is increasing size to capture economies of scale. Taller towers can be used to capture greater wind speeds, if the extra expense can be justified. Some of the largest machines have a ground-to-tip height of 130 meters (over 400 feet), making them very distinct features on the landscape.

Wind turbines are typically designed to operate within a specified speed range of about 4 to 25 m/s. Three wind speeds within this range are significant. The rated wind speed is the speed at which the turbine reaches its maximum (rated) power. The cut-in and cut-out wind speeds are, respectively, the speed at which the turbine starts to produce positive net power and the speed at which it is shut down to prevent mechanical damage. The range of wind speeds over which the turbine will operate is an important factor because it directly affects the capacity factor. If the wind speed is below the cut-in speed or above the cut-out speed, the turbine is essentially shut down and no power is produced.

Performance of a wind turbine is often depicted by the power curve, which shows the relationship between wind speed and turbine power output. Because of the variable nature of the wind resource, power curves should only be used as a general guideline of expected power output. Figure 9-6 shows a representative power curve for a 660 kW Vestas V47 wind turbine.

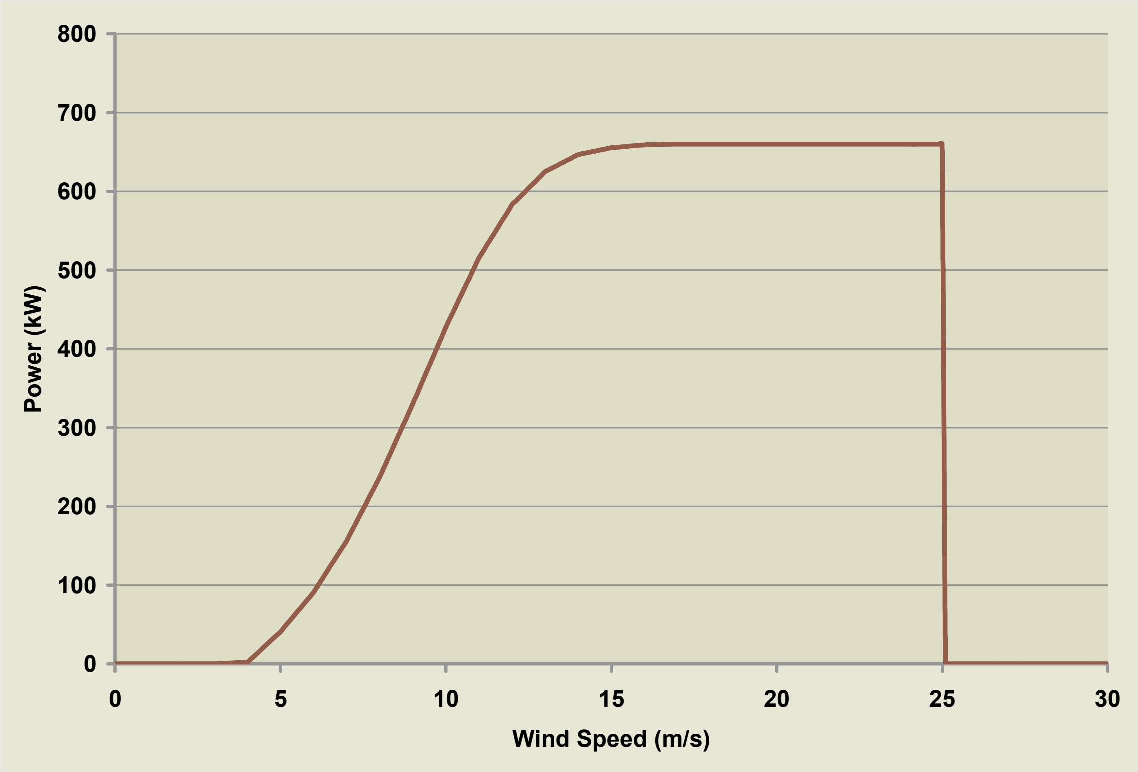

Figure 9-6. Vestas V47 Power Curve.

There are a number of turbine manufacturers around the globe. Most are from Europe with the largest being Vestas/NEG Micon, Enercon, and Bonus, which was recently purchased by Siemens. The only major US turbine manufacturer is GE Wind. Suzlon is a smaller manufacturer based in India, and Mitsubishi makes turbines in Japan.

Manufactures are increasingly focused on developing technology for larger size machines, with many targeting multi-megawatt machines for offshore applications, a major market in Europe. Concerns regarding shipping, transportation, constructability, crane availability, and long term O&M requirements limit the types of turbines that could be reasonably installed on Kauai. A 200 ton crane is currently available in the islands, but in the near term a 300 ton crane may be available from Onipa'a Crane and Rigging on the big island. The current crane availability restricts turbine size in the near term to below 1 MW, but if the 300 ton crane comes available, most commercially available turbines will be an option for Kauai. Use of large turbines may improve performance and cost slightly.

There are a variety of factors to consider with respect to constructing a wind project. Simply stated, if the project terrain is too remote or steep, special measures will have to be taken for construction that may increase the capital cost to non-economical levels. The most important factors to consider are ability to set up a large crane for erection of the towers and nacelles and transportation of the towers, nacelles and blades to the project site. The length of a utility-scale wind turbine blade is routinely over 25 meters (80 ft) and they are always shipped in one piece. Access by a suitable road must be considered when siting the project.

Projects on Kauai would involve a number of turbines totaling a name plate capacity around 7 MW as agreed with KIUC. Some options include: 10 Vestas V47s for a name plate capacity of 6.6 MW, 7 Bonus 1 MW turbines for 7.0 MW, 20 Suzlon 350 turbines for 7.0 MW, 5 GE 1.5 turbines for 7.5 MW (assuming crane availability), or a number of other options. Final turbine size and manufacturer should be made in consideration of actual wind data for the site, crane availability, cost, and other factors. A Vestas V47 660 kW turbine with a hub height of 50 meters has been used in the analysis herein. A different turbine may be more appropriate, but the V47 will give a reasonable idea of potential since the uncertainty in the available data is greater than any differences between turbines. A taller tower will almost always result in greater power production and should be weighed against constructability, cost, and visual impact.

9.4.3 Project Conceptual Design

This section provides a general description of the layout of a project placed on the high and moderate priority sites.

A wind plant in the Kalaheo area would likely involve one or two rows of wind turbines situated to the south west of Kalaheo on private lands or near the coast on Alexander & Baldwin land in areas of class 5 winds. The row(s) would be oriented approximately north-south to take advantage of the predominant winds from the east. A central power collection station and step-up transformer would add power directly to a major transmission line.

A wind plant in near Anahola, would involve constructing a new road (if one does not exist) onto the windy ridge of Puu Ehu on state land and placement of turbines along the ridge for maximum wind collection. From a common power collection point and transformer, new power lines would bring power to the nearby transmission line.

Wind farms near Omao, Hanapepe, or Maha'ulepu would be similar to the Anahola installation involving road construction, ridgeline turbine placement, and short transmission extensions.

A wind plant near Poipu would be similar to the Kalaheo project in that it would involve installation of turbines along flat terrain near the coast. It seems the best wind site is further from main transmission lines than at Kalaheo, so either a transmission extension or an upgrade of distribution lines leading to the wind site is needed.

A distributed wind development would likely involve single turbines and/or small groups of turbines at several of the following locations: along the ridge in the Kokee area (investigated here), south of the Port Allen airport, the point north of Kilauea, the ridgeline north of Hanamaulu, individual locations scattered in the Poipu and Kalaheo areas, and potentially smaller developments on the six sites described above. Turbines or groups of turbines would be connected to distribution lines via individual transformers. Land ownership would be mixed.

9.5 Power and Energy Production

The available wind data is not sufficient for a decisive assessment of energy production. Collection of wind data at 50 meters at prospective sites should be the first step in further pursuing wind power on Kauai. The available data along with the wind maps does give some indication of potential energy production, and Black & Veatch has made an analysis appropriate to the quality of data to give an indication of energy production potential. Use of 10 (or 3 in the case of Kokee) Vestas V47s with a 50 meter hub height has been assumed in all the analyses.

9.5.1 Plant Performance

Average wind speeds at the three sites where data is available varied in both pattern and intensity, as summarized in Figure 9-7. This data needed to be assessed for application at the actual project areas. Because the Kalaheo and Anahola potential wind energy development sites are significantly far from their respective wind data towers, Black & Veatch utilized the wind map to approximate the ratio of wind speeds between the data location and the proposed turbine location. Furthermore, as the wind data collected at all three sites were lower than the proposed wind turbine's hub height, wind speeds were adjusted upward to 50 meters using a wind sheer factor of 0.1 for the two ridgeline sites (Anahola and Hanapepe) and 0.18 for the relatively flat costal site (Kalaheo). It can be seen in Figure 9-8 that the intensity is similar for these three wind sites but the distribution differences remain.

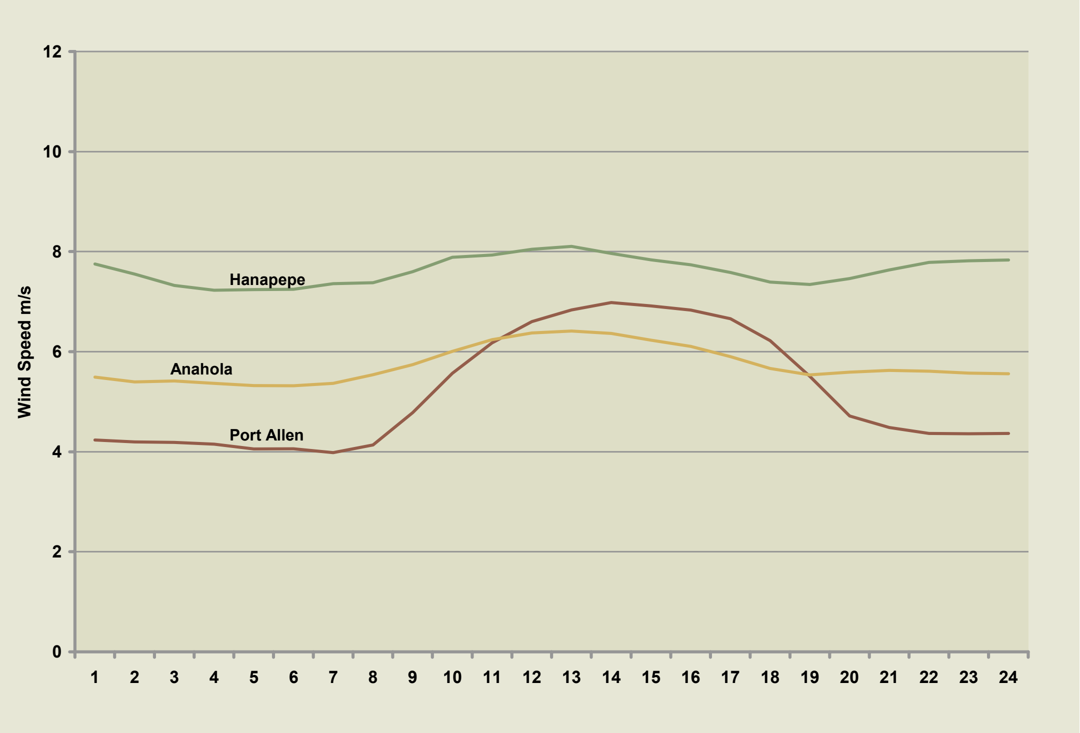

Figure 9-7. Measured Anemometer Site Hourly Average Wind Speeds.

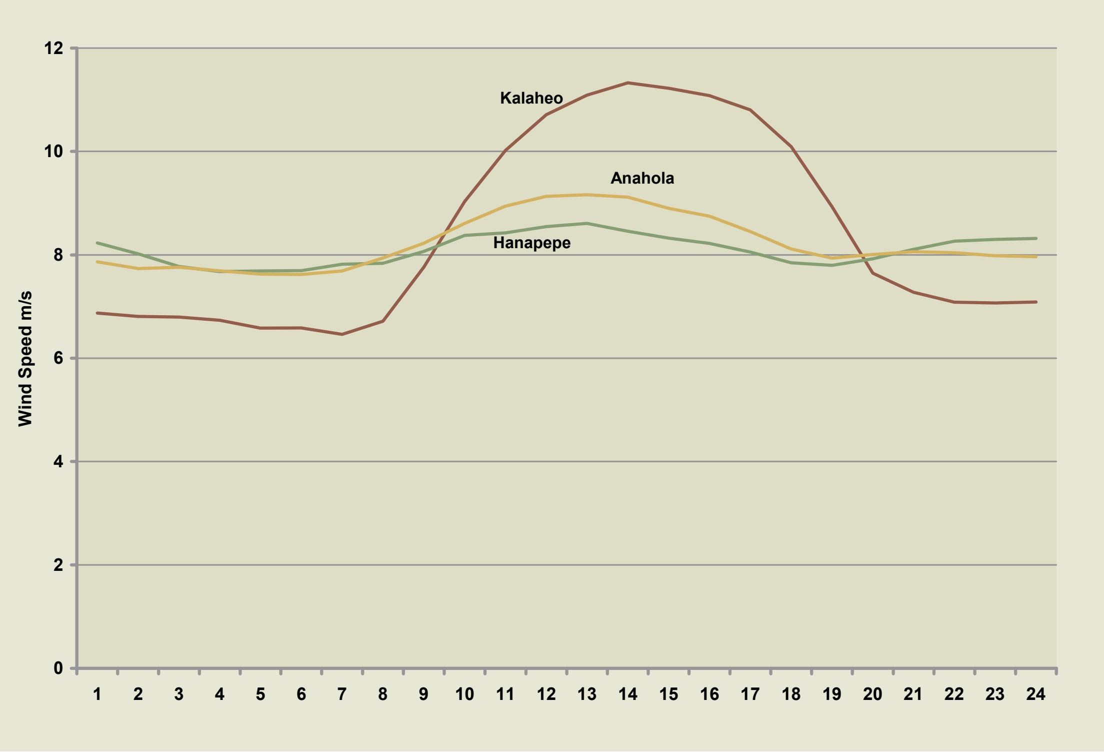

Figure 9-8. Estimated Turbine Site Hourly Average Wind Speeds.

Based on the anemometer data and information form the validated wind map, Black & Veatch developed capacity factor and annual production estimates for each of the wind sites, as shown in Table 9-2. Not having a specific site layout, specific equipment selected, or detailed site data, a loss factor of 15 percent was applied to the theoretical output of all proposed projects to account for: plant transmission losses, plant electrical consumption, blade soiling, array losses, planned and unplanned outages of turbines or the grid, and other factors effecting overall energy yield. A more precise estimate can be calculated once a specific project is proposed.

Table 9-2. Wind Area Production Estimates.

Site	Nameplate Capacity, MW	Capacity Factor, percent	Annual Generation, GWh/yr
Kalaheo	6.6	35%	20.2
Omao	6.6	36%	20.8
Hanapepe	6.6	36%	20.8
Kokee	1.98	36%	6.2
Anahola	6.6	34%	19.7
Poipu	6.6	31%	17.9
Maha'ulepu	6.6	36%	20.8

9.5.2 Operating Profile

A detailed production profile has been provided for a site in the three areas having local anemometry data: Kalaheo, Hanapepe, and Anahola.

Kalaheo

Kaleheo site performance estimates were made using the Port Allen 10 meter anemometer data scaled up to 50 meters using a wind sheer factor of 0.18 (appropriate for flat terrain). The data was then further scaled to the better wind site south east of Kalaheo using a ratio of 8.5/7 which is the ratio of wind speeds shown on the verified wind speed at 50 m map. These speeds were modeled with the Vestas V47 power curve, air density information and other factors to estimate capacity factor and the seasonal and diurnal power variation. Due to the distant location and low measurement height of the wind data, the information herein is only an indication of pattern and intensity. Data at or near hub height from the proposed site is necessary to give a firm estimate of production. Analyses yielded an approximate capacity factor of 35 percent at 50 meters for an annual energy yield of 20 GWh. Figure 9-9 shows power consumption for a Thursday in April 1996 with projected power production from a 6.6 MW Kalaheo project. The projected production from this coastal site has an afternoon peak in all seasons, closely following the load pattern.

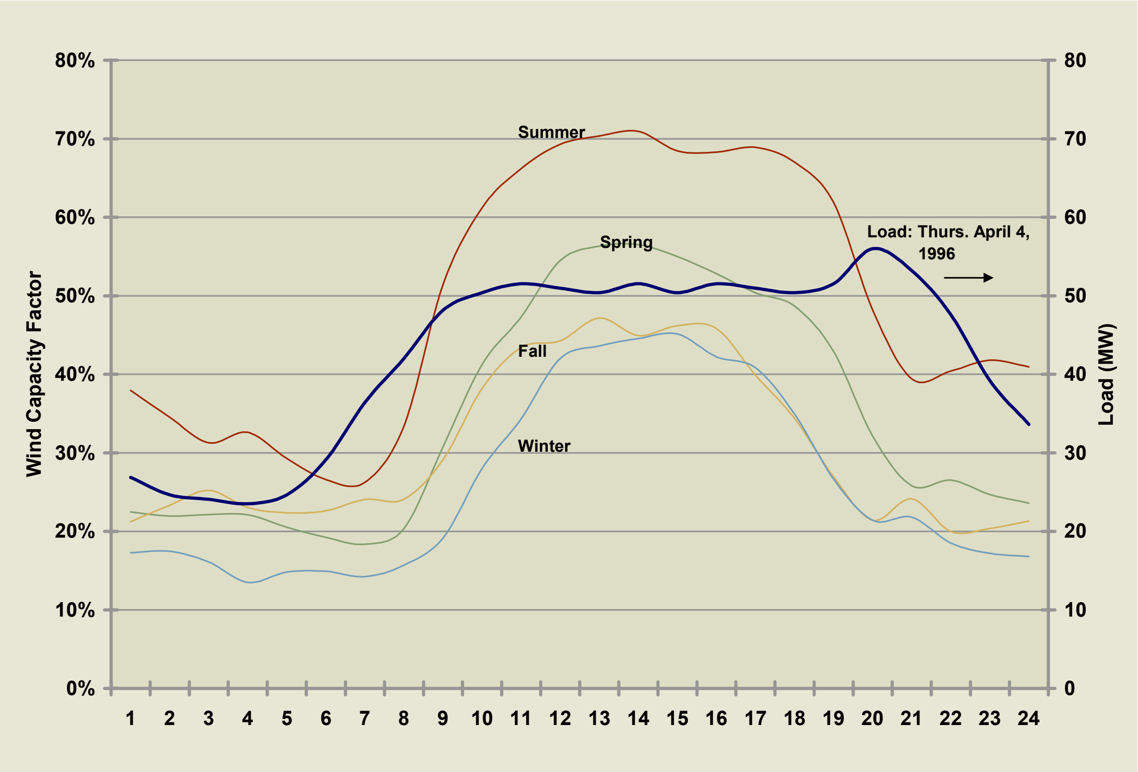

Figure 9-9. Diurnal and Seasonal Capacity Factor with KIUC Summer Loads and Project Output, Kalaheo Area.

Hanapepe

Hanapepe site performance estimates were made using the 27 m (90 ft) anemometer data scaled up to 50 meters using a wind sheer factor of 0.1 (appropriate for ridgeline terrain). Black & Veatch did not have the precise location of the anemometer at the time of writing this report and did not assume a location correction factor as with the other two sites with data. The location of the anemometer appears close enough to a likely site to use the scaled data directly. The wind speeds were then modeled with the Vestas V47 power curve, air density information and other factors to estimate capacity factor and the seasonal and diurnal power variation. Due to the unknown siting of the anemometer, the production information herein is only an indication of pattern intensity. Data at or near hub height from the proposed site is necessary to give a firm estimate of production.

Analyses yielded an approximate capacity factor of 36 percent at 50 meters on the anemometer site for an annual energy yield of 21 GWh. Figure 9-10 shows power consumption for a Thursday in April 1996 with projected power production from a 6.6 MW Hanapepe project. Projected output from this ridgeline site has a fairly flat profile through all seasons.

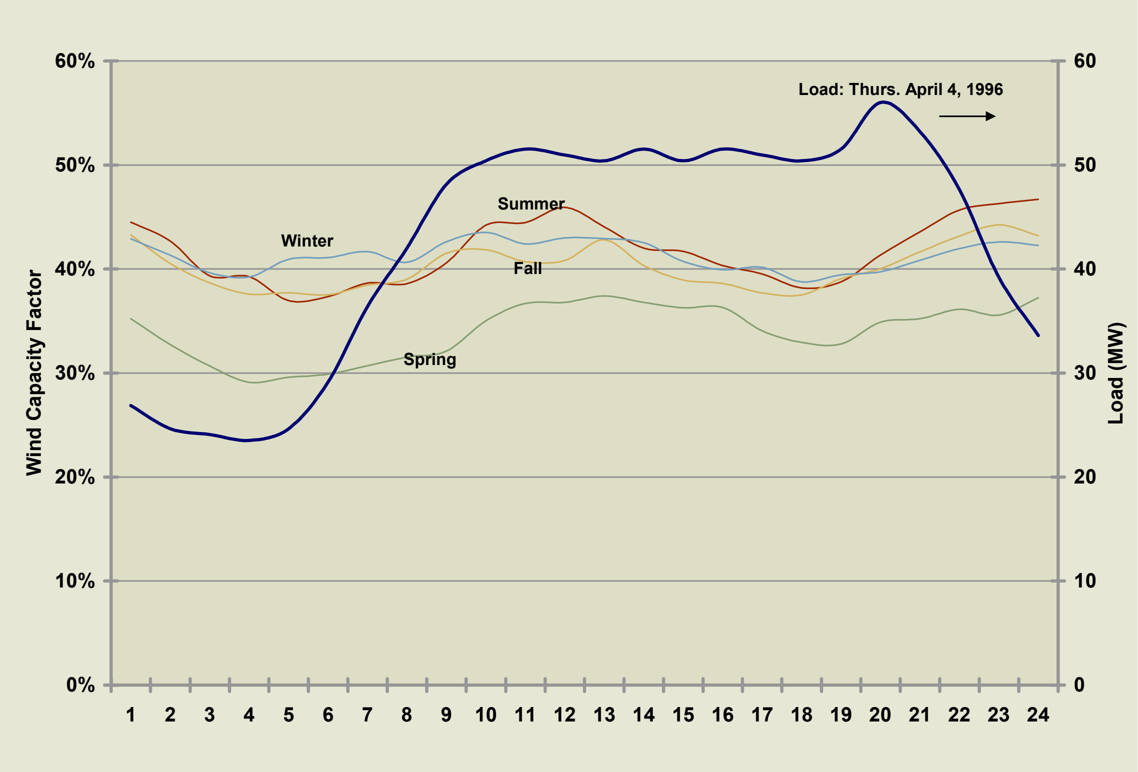

Figure 9-10. Diurnal and Seasonal Capacity Factor with KIUC Summer Loads and Project Output, Hanapepe Area.

Anahola

Anahola site performance estimates were made using the using 27 m (90 ft) anemometer data scaled up to 50 meters using a wind sheer factor of 0.1 (appropriate for ridgline terrain). The data was then further scaled to the better wind on the ridge of Mt. Puu Ehu using a ratio of 8/6 which is the ratio of wind speeds shown on the verified 50m wind speed map. These speeds were then modeled with the Vestas V47 power curve, air density information and other factors to estimate capacity factor and the seasonal and diurnal power variation. Due to the distant location of the wind data, the information herein is only an indication of pattern and intensity. Data at or near hub height from the proposed site is necessary to give a firm estimate of production.

Analyses yielded an approximate capacity factor of 34 percent at 50 meters for an annual energy yield of 19 GWh. Figure 9-11 shows power consumption for a Thursday in April 1996 with projected seasonal capacity factors for a 6.6 MW Anahola project. The projected production from this site has a modest afternoon peak in all seasons, somewhat following the load pattern.

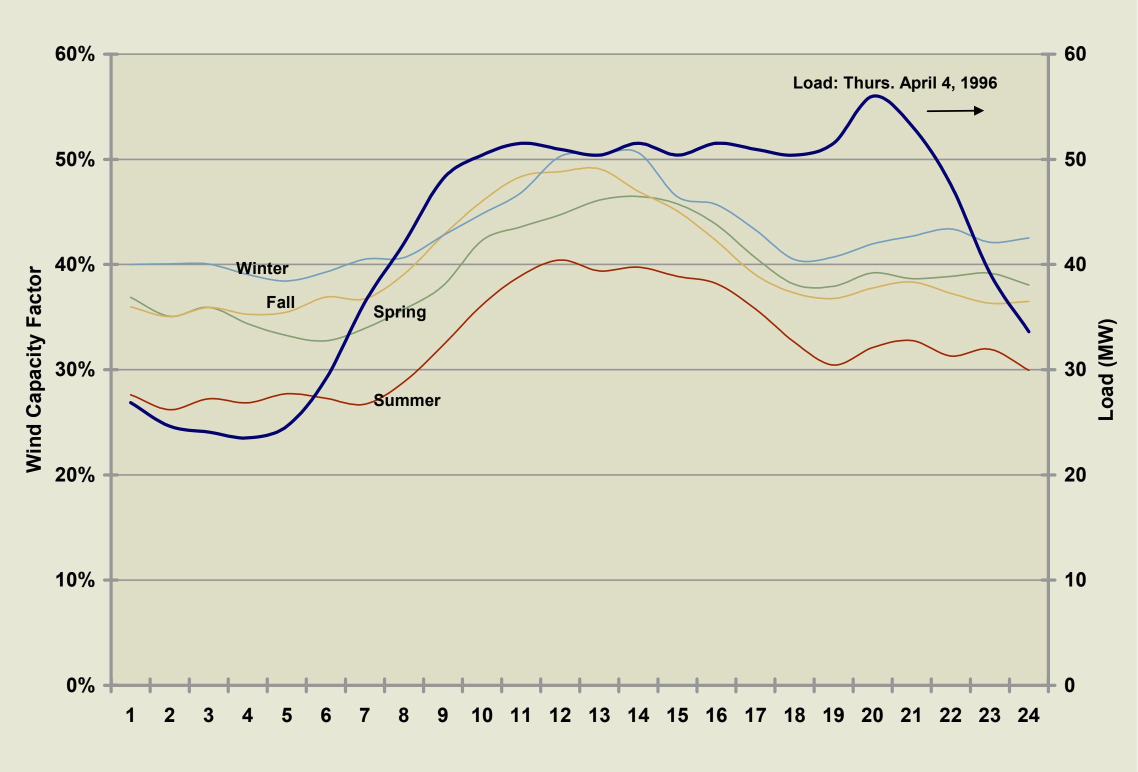

Figure 9-11. Diurnal and Seasonal Capacity Factor with KIUC Summer Loads and Project Output, Anahola Area.

9.6 Cost of Energy

9.6.1 Capital Costs

Three general capital cost scenarios were developed: (1) Flat 6.6 MW, (2) Ridge 6.6 MW, and (3) Ridge 2 MW. The first assumed a relatively flat and accessible 6.6 MW project site representing the Kalaheo and Poipu sites. The second assumed a 6.6 MW ridgeline site to represent the Omao, Hanapepe, Anahola, and Maha'ulepu sites. The third scenario assumed a 2 MW ridgeline site to represent the Kokee site. The main difference between the flat and ridgeline costs analyses was that labor costs were increased by 50 percent and crane costs by 25 percent to represent the difficulties of working in rough terrain.

The costs for each project assume a limited amount of civil works to bring roads and transmission to the wind farm. The Hanapepe and Anahola sites are not readily accessible and will require significant infrastructure upgrades. An additional $1.7 million (5 miles of road and 3 miles transmission) has been allocated for Hanapepe and an additional $0.9 million (3 miles road, 1 mile transmission) has been allocated for Anahola to account for additional road and transmission extensions which would likely be required.

For each project, indirect costs were added using 10 percent of material and labor costs plus $1,000,000 to cover development costs such as permitting, environmental studies, outreach, etc. This fixed development cost makes the smaller project significantly more expensive on a per MW capacity basis. Installing three distributed generation installations for a total capacity similar to the central plant projects would decrease the cost per MW capacity closer to the level for the other projects, but development would still be more expensive since separate permits, road improvements, etc., would be required for each project.

Based on the foregoing assumptions, the resulting capital cost estimates are shown in Table 9-3.

Table 9-3. Kauai Wind Project Capital Costs

Sites	Scenario	Capital Cost	Cost per kW
Kalaheo, Poipu:	Flat 6.6 MW	$10,750,000	$1,630
Omao, Maha'ulepu:	Ridge 6.6 MW	$11,150,000	$1,690
Hanapepe	Ridge 6.6 MW + T&R*	$12,850,000	$1,945
Anahola	Ridge 6.6 MW + T&R*	$12,050,000	$1,825
Kokee	Ridge 2 MW	$4,450,000	$2,250

*Additional transmission and road costs

9.6.2 Operating and Maintenance Costs

The operating and maintenance costs assumed one full time employee at a cost of $90,000/year. Major maintenance activities would be contracted as required. Operating and maintenance costs varied with scenario and the results are listed in Table 9-4. The main factor effecting O&M costs was number of turbines. A capacity factor of 35 percent was assumed for variable O&M which approximately matches most of the easily developable wind sites.

Table 9-4. Kauai Wind Project Annual O&M Costs.

Scenario	Fixed, $/yr	Variable, $/yr	Total O&M, $/yr	Total $/MWh
Flat 6.6 MW	$257,765	$35,000	$292,800	14.6
Ridge 6.6 MW	$258,149	$35,000	$293,150	14.7
Ridge 2 MW	$148,698	$10,800	$159,500	26.6

9.6.3 Applicable Incentives

There are several federal incentives available for the development of wind energy facilities. The federal production tax credit provides an $18/MWh incentive for ten years following the initial commercial operation date of the facility. A reduced depreciation cycle of five years is also offered. At the state level, there is a 20 percent state tax credit, with a cap of $250,000, on the installation of wind energy equipment. The project owner must be a taxable entity to receive these incentives. The PTC and state credit are included for the developer ownership scenario in the life-cycle cost analysis. Various federal grants and low interest loan programs may also be applicable to these projects; however, the exact impact of these programs is uncertain and not quantified at this time. Therefore, no incentives are included for the KIUC ownership scenario in the life-cycle cost analysis.

9.6.4 Life-cycle Economics

The life-cycle cost of providing power from each of the proposed wind energy projects was evaluated by calculating the levelized cost. Table 9-5 provides a summary of the wind project performance and economic assumptions as well as the results of the life-cycle cost analysis. Figure 9-12 shows an example life-cycle cost calculation for the Omao wind project.

Table 9-5. Wind Life-Cycle Economic Assumptions ($2005).

	Unit	Kalaheo	Omao	Hana-pepe	Kokee	Anahola	Poipu	Maha'-ulepu
Capacity	MW	6.6	6.6	6.6	1.98	6.6	6.6	6.6
Capital Cost	$/kW	1628	1689	1947	2249	1826	1628	1689
First Year Fixed O&M	$/kW-yr	39.06	39.11	39.11	75.1	39.11	39.06	39.11
First Year Variable O&M	$/MWh	1.73	1.68	1.68	1.73	1.78	1.95	1.68
First Year Fuel Cost	$/MBtu	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Net Plant Heat Rate	Btu/kWh	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Capacity Factor	percent	35%	36%	36%	36%	34%	31%	36%
KIUC Levelized Cost	2009$/ MWh	64.46	64.24	70.76	95.88	71.68	72.77	64.24
KIUC Premium	2009$/ MWh	(90.10)	(90.32)	(83.80)	(58.68)	(82.88)	(81.79)	(90.32)
Developer Levelized Cost	2009$/ MWh	75.58	75.70	86.55	112.12	87.05	87.12	75.70
Developer Premium	2009$/ MWh	(78.98)	(78.86)	(68.01)	(42.44)	(67.51)	(67.44)	(78.86)

The levelized cost of generating power from the seven wind projects with KIUC ownership ranged from $64/MWh to $73/MWh for the 6.6 MW projects to $96/MWh for the 2 MW project. No wind site stands out as being vastly superior to others. This gives KIUC good flexibility (and negotiation position) in siting the first projects in the location deemed most suitable. When the avoided capacity and energy costs were considered, the levelized cost premiums ranged from ($90)/MWh to ($59)/MWh. These results indicate that wind is attractive economically compared to KIUC's forecast of avoided costs.

The levelized cost of generating power with developer ownership and a PPA with KIUC was also calculated. The results are very close to KIUC ownership. The value of the PTC for the private developer is nearly equal to the value of low cost financing for KIUC.

Omao

Wind

Plant Input Data		Economic Input Data	Rate	Escalation
Capital Cost ($1,000)	12,561	First Year Fixed O&M ($1,000)	290.52	3.0%
Total Net Capacity (MW)	6.60	First Year Variable O&M ($1,000)	39.36	3.0%
Capacity Factor	36%	Fuel Rate ($/MWh)	0.00	3.0%
Full Load Heat Rate, Btu/kWh (HHV)	-			
Debt Term	25			
Project Life	25			
		Present Worth Discount Rate	5.0%	
Hours per Year	8,760	Levelized Fixed Charge Rate	7.10%	

Year	Annual Capital Cost ($1,000)	Fixed O&M ($1,000)	Variable O&M ($1,000)	Fuel Rate ($/MBtu)	Fuel Cost ($1,000)	Total Cost ($1,000)	PW Total Cost ($1,000)	Busbar Cost ($/MWh)	PW Cost ($/MWh)	Avoided Capacity Cost ($/kW)	Avoided Energy Cost ($/MWh)
2009	891	291	39	-	-	1,221	1,163	58.67	55.88	0.00	111.89
2010	891	299	41	-	-	1,231	1,117	59.15	53.65	0.00	121.46
2011	891	308	42	-	-	1,241	1,072	59.63	51.51	0.00	131.10
2012	891	317	43	-	-	1,252	1,030	60.14	49.48	0.00	133.40
2013	891	327	44	-	-	1,263	989	60.66	47.53	0.00	139.93
2014	891	337	46	-	-	1,274	950	61.19	45.66	160.34	146.48
2015	891	347	47	-	-	1,285	913	61.75	43.88	162.00	155.09
2016	891	357	48	-	-	1,297	878	62.31	42.18	160.15	159.54
2017	891	368	50	-	-	1,309	844	62.90	40.54	192.08	155.25
2018	891	379	51	-	-	1,322	811	63.50	38.98	192.80	164.57
2019	891	390	53	-	-	1,335	780	64.12	37.49	192.35	168.47
2020	891	402	54	-	-	1,348	751	64.76	36.06	183.14	166.80
2021	891	414	56	-	-	1,362	722	65.42	34.69	203.74	163.22
2022	891	427	58	-	-	1,376	695	66.10	33.38	200.11	168.86
2023	891	439	60	-	-	1,390	669	66.79	32.13	196.32	159.73
2024	891	453	61	-	-	1,405	644	67.51	30.93	214.88	164.41
2025	891	466	63	-	-	1,421	620	68.25	29.78	202.03	166.83
2026	891	480	65	-	-	1,436	597	69.02	28.68	206.07	170.16
2027	891	495	67	-	-	1,453	575	69.80	27.62	210.19	173.57
2028	891	509	69	-	-	1,470	554	70.61	26.61	214.40	177.04
2029	891	525	71	-	-	1,487	534	71.45	25.64	218.68	180.58
2030	891	540	73	-	-	1,505	514	72.30	24.72	223.06	184.19
2031	891	557	75	-	-	1,523	496	73.19	23.83	227.52	187.87
2032	891	573	78	-	-	1,542	478	74.10	22.98	232.07	191.63
2033	891	591	80	-	-	1,562	461	75.04	22.16	236.71	195.46

Levelized Bus-bar Cost, $/MWh	**64.28**
Net Levelized Cost ($1,000)	**1,337.96**
Levelized Avoided Capacity Cost, $/MWh	**-**
Levelized Avoided Energy Cost, $/MWh	**154.56**
Levelized Cost Premium, $/MWh	**(90.28)**

Figure 9-12. Life-cycle Cost for Omao Wind Project.

9.7 Advantages and Disadvantages of Technology

A discussion of each of the qualitative screening criteria is provided in this section.

9.7.1 Fit to KIUC Needs

Although wind cannot provide firm capacity, KIUC interest for reduced fuel consumption is well met by wind power as shown by the savings demonstrated in Table 9-5 KIUC has sufficient generation to cover all current loads and flexible generation such that it can compensate for the intermittency of wind power, at least at small elvels of penetration. In the long term, KIUC would do well to consider project sites with wind profiles that match load profiles to maximize effective penetration of wind. One such site, Kalaheo, seems to have this type of a profile. The technology is modular in scale and, as such, an appropriate size project has been identified in dialogue with KIUC such that it will be readily integrated at a reasonable cost.

9.7.2 Environmental Impact

Wind is a fuel free energy source and as such has significant emissions reduction benefits. These reductions are beneficial for local air quality and for meeting current and future emissions regulations.

Impact to native birds and bats should be studied and addressed to ensure that the wind turbines will not have a detrimental impact. In general, siting of wind turbines to avoid bird and bat feeding routes and migratory paths can effectively minimize bird and bat mortality to a negligible level. The Newell's Shearwater (NS), a threatened bird species on Kauai, is of particular concern. The NS is found mainly on Kauai and their numbers are decreasing over time in spite of conservation efforts. Wind power may potentially impact these birds, although careful planning appears to offer many potential mitigation measures. The NS young are attracted to light and are vulnerable to distraction and grounding on their first flights. To minimize impacts, wind turbine development could proceed using lower tower heights and configurations not requiring FCC warning lights. NS fly lower to the ground near the coast as opposed to inland; an inland wind development would have a greater chance of being below the NS flight path. NS have been observed to use flight corridors to go from the island to the sea. A study during the summer and fall (periods of high activity) could be conducted make sure the proposed wind development site was not in one of these flight corridors. Furthermore the vast majority of NS movement happens between the hours of 4-6:30 am and 6-9 pm and turbines could be shut down during this time during the late summer and fall if bird strikes became an issue.

Erosion potential during construction on some of the steeper sites on Kauai may be of concern and should be addressed both in site selection and in construction planning.

Wind farms are sited over large areas of land. Turbines need to be spaced out to ensure that the wake of one turbine does not affect downstream turbines. A rule-of-thumb estimate for spacing is 5 diameters by 8 diameters. A 50-meter turbine would require spacing of 250 meters by 400 meters (820 x 1,312 ft). However, the actual turbine, access roads, and transmission lines typically take up less than 5 percent of this area and the surrounding land can be used for other purposes. Agriculture has been shown to be a particularly good mix. There are large agricultural areas of Kauai with good wind potential.

9.7.3 Socioeconomic Impact

The socioeconomic impacts of wind development are relatively modest. One full-time operations and maintenance job as well as contract work will be provided by developing a 6.6 MW project. Construction employment impacts will be higher, but short term. Further, most of the project capital cost is related to turbine manufacture, which will like take place out-of-state and possibly outside the US.

Wind power can provide an income source for local land owners in the form of land leases while occupying a small percentage of the land.

9.7.4 Incentives and Barriers

There are several incentives to developing wind energy on Kauai. First, wind energy has good overall public acceptance and a majority of people have a positive impression of wind energy. This can be beneficial in any public review process. Also, wind is modular and replicable so that KIUC can get start with a small wind project and implement more at a time and scale deemed appropriate. Sites with wind data already being collected, sites near to load centers, and sites with an actively interested land owner or community have further incentives.

Barriers to wind development on Kauai are also present. The lack of wind industry infrastructure in Hawaii will likely mean outsourcing to the mainland for technical and equipment needs of the plant. Hurricane exposure is another potential liability of a wind project on Kauai, though some manufacturers rate their turbines to survive 150 mile per hour winds, and insurance for projects is available even in hurricane prone areas. A few of the sites proposed may require development of additional infrastructure such as roads and transmission lines, notably Anahola and Hanapepe sites.

Visual impacts are perhaps the largest concern. The location of the Kokee, Poipu, Maha'ulepu, and Omao projects near tourist areas or in particularly scenic areas may be an issue. The Kalaheo, Hanapepe, and Anahola sites would likely have a lower visual presence, but would still be visible to nearby residences. Utility-scale wind turbines are large, tall, moving machines that can be visible for miles. Some individuals find the view of operating wind turbines pleasant, and some do not. The visual impact is therefore difficult to predict. A great deal of study has been given to the aesthetic aspects of wind farm development. As such, aesthetics have generally improved from the cluttered, frenetic style of early California wind farms (Figure 9-13) to more graceful installations such as that shown in Figure 9-14. Larger turbines developed in recent years also spin at lower speeds than past models, and this has generally been found to be more soothing to the eye. Once a specific project location is determined, computer simulations can be made to determine the potential visual impacts to surrounding view sheds.

Figure 9-13. Example of Early Wind Farm Development in California.[111]

Figure 9-14. Coastline Wind Power Installation in Denmark.[112]

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[111] Picture from http://www.ifb.uni-stuttgart.de/~doerner/win14.gif.
[112] Picture from Danish Wind Turbine Manufacturers Association, http://www.windpower.dk.

Local participation can be a powerful tool for the project. Local officials and citizens may be more willing to accept a facility if they have open access to all information about the facility; have the authority and funding to independently monitor the project development and proposed site; and are allowed input over how it is constructed, operated, and maintained.

The noise and visual impact of wind projects and corresponding property value concerns have lead to community opposition of numerous wind farms across the country. Although steps can be taken in project design to minimize visual impacts and enhance the aesthetic appeal of the project, community support is vital during all stages of project development. KIUC might consider sending out staff to address local citizen groups on a regular basis. If these groups are viewed as "partners," the project will have a better chance of succeeding.

9.8 Next Steps

The development of a wind project of any magnitude is a complex balance of permitting, land acquisition, power agreements and engineering. It is important to follow the correct steps to minimize the project development timeframe while avoiding financial risks.

The steps described here should be used as a guideline for proceeding with the project development. They are listed in a chronological order that should maintain forward progress for the project:

- Preliminary discussions with potential landowners to assess feasibility of identified project locations
- Meteorological tower installation and data collection
- "Test the Waters" review – public opposition and permitting review
- Land lease / purchase agreements
- Environmental impact review
- Interconnection and transmission study

These tasks will make up the basis of the preliminary project development stage.

10.0 Landfill Gas

There is only one viable landfill gas project on Kauai, located at the Kekaha landfill. (There is one smaller landfill, but it is not suitable for development.) Black & Veatch estimated the energy production of this project after landfill closure in 2009. A project based on reciprocating engine technology could produce about 800 kW. The results of this assessment are detailed here.

10.1 Basis for Assessment

Black & Veatch reviewed the Landfill Gas (LFG) Utilization Feasibility Study for the Kekaha Landfill by SCS Engineers dated April 2004. This report provided information about the operating landfill at Kekaha with financial analysis results from the EPA LMOP E-PLUS program.

Three scenarios were evaluated by SCS; the primary option utilized an internal combustion (IC) engine for power generation.

10.2 Assessment of Contributing Resource

The source of the LFG is the Kekaha Landfill. It opened in 1953 and was originally scheduled to close in 2004. A closure extension until 2009 has recently been granted. SCS modeled landfill gas production assuming a 2004 closure. Black & Veatch extended the model to account for closure in 2009. The landfill is currently producing LFG, but it is not collected. A project could conceivably come on-line before 2009 to take advantage of gas being produced now. Additional capacity could be added later after the landfill is completely capped. However, such generation staging was not assumed for this study.

It seems that few formal records were kept for waste deposits and waste-in-place (WIP) until recently. It is estimated by the landfill operators that the annual deposit rate was 14,600 tons per year until 1993. At that point, records show a dramatic increase up to the current rate of 79,000 tons per year.

SCS used a program called E PLUS that was developed by the EPA LMOP to estimate landfill gas generation potential. The program uses a first order decay model based on the amount of WIP and empirical gas generation constants. Based on the SCS model, the year of the maximum WIP for the Kekaha Landfill will be 2004, the year of closure. Accordingly, the maximum gas generation will occur that year. SCS estimated the maximum gas flow will be 379 cubic feet per minute (cfm). Thereafter, the gas flow will decline, with the estimate for 2018 being 243 cfm.

Black & Veatch has modified the analysis to determine the LFG generation potential assuming a closure date of 2009. The analysis was based on the first order decay equation:

$$Q_M = \sum_{i=1}^{n} 2\, k\, L_o M_i \left(E^{kt_i}\right)$$

where:

i = year, through the last projection year (n)
Q_M = maximum expected LFG production flow rate (m^3/yr)
K = methane generation rate constant (1/yr)
L_o = methane generation potential (m^3/Mg)
M_i = mass of solid waste disposed of in the i^{th} year (Mg)
t_i = age of the waste disposed in the i^{th} year (years)

Black & Veatch's gas estimates are shown in Figure 10-1. In this case, the maximum gas flow is approximately 465 cfm and occurs in 2009.

Very little data has been provided regarding the quality of the gas. It is stated that the measured methane content is 40 percent. This is considered low for LFG and is borderline for use in IC engines. Methane typically constitutes 45 to 50 percent of the landfill gas. Other important qualities that have not been discussed are the oxygen, moisture, siloxane, halide, chloride and sulfur (H2S) contents. High oxygen content (more than 2 percent) can be an indicator of imbalanced gas collection flows. With adjustments, the oxygen level can be reduced and methane production increased.

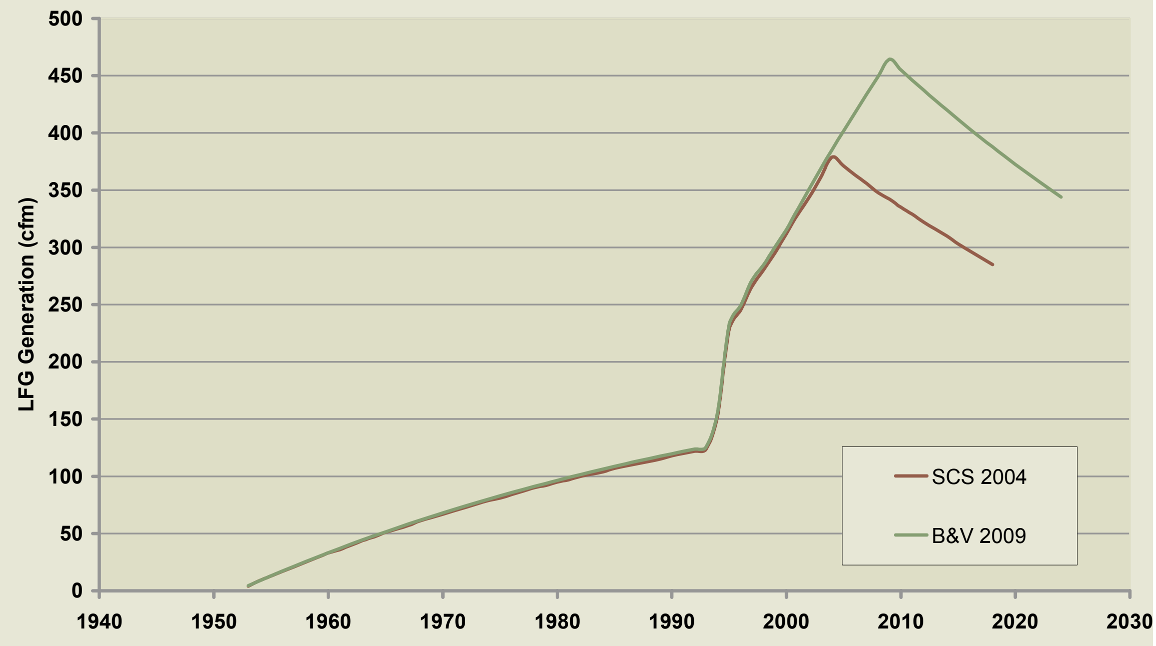

Figure 10-1. LFG Generation Estimates by Year.

10.3 Project Option Screening

Various uses can be envisioned for the LFG from Kekaha Landfill. The most conventional is combustion in an IC engine at the landfill for generation of electricity. Others include direct use of the gas for heating or displacement of fossil fuel consumption in a nearby, existing engine generator. These could be options in Kauai, but Black & Veatch is unaware of firm offtakers proposed for either. Only the IC engine option has been considered in this review.

10.4 Project Technical Description

Compared to many of the other renewable energy options, development of landfill gas projects is relatively straightforward. One of the more significant aspects will be development of gas collection facilities, which Kekaha does not currently have. The collection system consists of vertical gas wells, wellheads, blowers and gas cleanup equipment. Flares are also required for destruction of LFG during periods of engine outages. The Landfill is not currently required by law to have or install these collection facilities. The balance of the project consists of installing an engine generator and interconnecting the project to the electrical grid.

10.5 Power and Energy Production

10.5.1 Plant Performance

The plant efficiencies for IC engines are typically in the range of 20 to 30 percent. Engine generators burning LFG that are considered "new and clean" typically have an efficiency of about 30 percent. This equates to a net plant heat rate of about 11,500 Btu/kWh. Historical data for LFG projects show that the heat rate may increase up to 14,500 Btu/kWh, depending on the effectiveness of the O&M plan. In addition, due to part load inefficiencies, the net plant heat rate will degrade over the life of the project as the amount of gas declines.

Based on the gas production estimates, the plant capacity will be approximately 810 kW at the time of commissioning in 2009. The capacity will remain constant at 810 kW over the first five years as the total amount of gas generated exceeds the fuel burn rate of the engine. Over time, the capacity will dwindle as the gas supply decreases. Because of the decreasing generation, it is assumed that the project life will be limited to 15 years. Based on the model predictions for gas flow in 2024, the project capacity will decrease to around 703 kW.

10.5.2 Operating Profile

With a capacity factor as high as 85 percent, LFG plants are baseloaded. Landfills typically provide very steady gas flows. There is very rarely opportunity for gas storage. All gas that is generated while the plant is in an outage will be flared. This plant will operate similarly and provide baseload power.

10.6 Cost of Energy

10.6.1 Capital Cost

Black & Veatch has estimated the total capital cost of the LFG project, shown in Table 10-1. The engine generator set line item cost was provided by a Caterpillar distributor. The costs for the installation of the engine set and the electrical system were based on Black & Veatch historical data. LFG collection system costs can be quite varied. This estimate is based on an expected number of gas wells and corresponding horizontal collection lines for a landfill of this size.

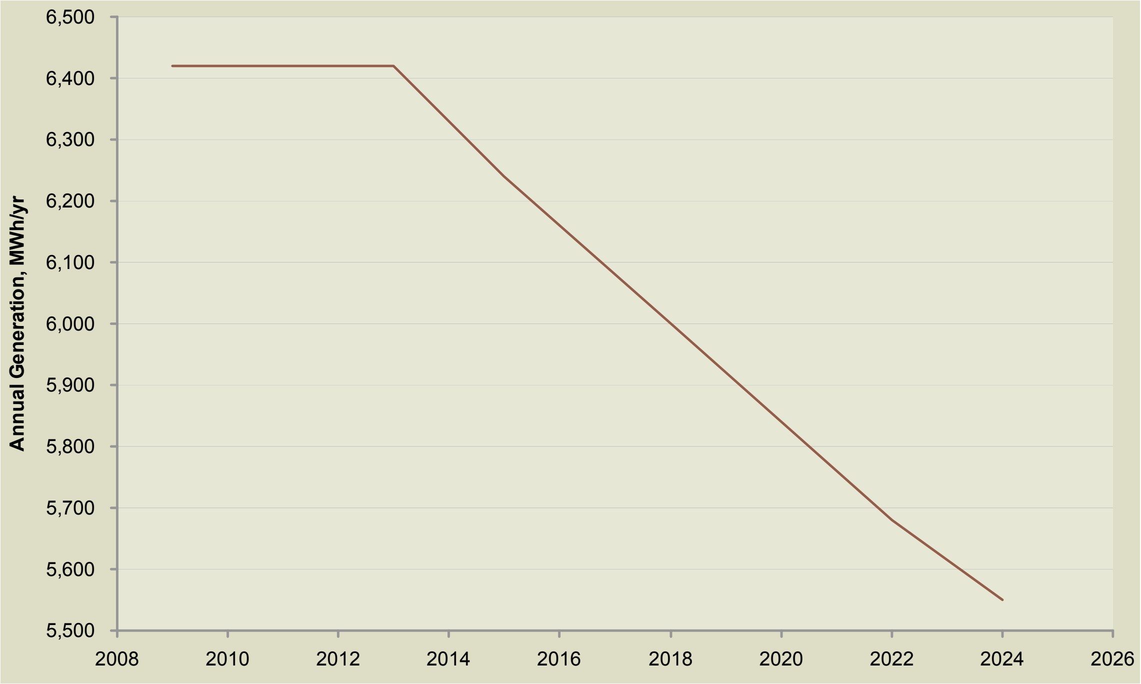

Figure 10-2. Annual Electrical Generation.

Table 10-1. LFG Capital Cost Estimate.

Construction Item	**Cost**
Engine Generator Set	599,000
Electrical System	301,000
LFG Collection System	1,580,000
Total Direct Cost	*2,480,000*
Indirect Cost	*748,000*
Total Capital Cost	**3,228,000**
Total Capital Cost, $/kW (810 kW)	**3,965**

10.6.2 Operating and Maintenance Costs

Black & Veatch has estimated that the first year O&M cost will be $190,000. This is inclusive of fixed and variable costs. It is assumed that one full time staff will operate and maintain the facility, likely remotely. Other items included are planned replacements of bearing and heads and routine maintenance such as changing the oil. Periodic engine rebuilds are also included as planned maintenance costs.

10.6.3 Applicable Incentives

There are several federal incentives available for the development of landfill gas power generation facilities. The federal production tax credit provides a $9/MWh incentive for five years following the initial commercial operation date of the facility, however the facility must be owned by a taxable entity to claim this credit. The PTC is included in the life-cycle cost analysis for the developer ownership scenario. Various federal grants and low interest loan programs would be applicable to these projects; however, the exact impact of these programs is uncertain and not quantified at this time. Therefore, no incentives are included for the KIUC ownership scenario in the life-cycle cost analysis.

10.6.4 Life-cycle Economics

The life-cycle cost of providing power from the potential landfill gas-to-energy project at the Kekaha landfill was calculated with the levelized cost. The project performance and economic assumptions as well as the results of the life-cycle cost analysis are presented in Table 10-2. Figure 10-3 shows an example life-cycle cost calculation for the Kekaha Landfill Gas project.

Table 10-2. Landfill Gas Life-Cycle Economic Assumptions ($2005).

	Unit	Kekaha Landfill
Capacity	MW	0.8
Capital Cost	$/kW	3,965
First Year Fixed O&M	$/kW-yr	111
First Year Variable O&M	$/MWh	16
First Year Fuel Cost	$/MBtu	-
Net Plant Heat Rate	Btu/kWh	11,491
Capacity Factor	percent	86%
KIUC Levelized Cost	2009$/MWh	98.83
KIUC Premium	2009$/MWh	(61.54)
Developer Levelized Cost	2009$/MWh	119.96
Developer Premium	2009$/MWh	(40.40)

The levelized cost of the landfill gas project was calculated to be about $99/MWh, with a premium of about ($62)/MWh. The favorable economics of the landfill gas project relative to forecasted avoided costs are due, in part, to the free fuel and the high capacity factor.

Kekaha Landfill

Landfill Gas

Plant Input Data		**Economic Input Data**	**Rate**	**Escalation**
Capital Cost ($1,000)	3,633	First Year Fixed O&M ($1,000)	101.69	3.0%
Total Net Capacity (MW)	0.81	First Year Variable O&M ($1,000)	110.43	3.0%
Capacity Factor	86%	Fuel Rate ($/MWh)	0.00	3.0%
Full Load Heat Rate, Btu/kWh (HHV)	11,491.00			
Debt Term	15			
Project Life	15			
		Present Worth Discount Rate	5.0%	
Hours per Year	8,760	Levelized Fixed Charge Rate	9.63%	

Year	Annual Capital Cost ($1,000)	Fixed O&M ($1,000)	Variable O&M ($1,000)	Fuel Rate ($/MBtu)	Fuel Cost ($1,000)	Total Cost ($1,000)	PW Total Cost ($1,000)	Busbar Cost ($/MWh)	PW Cost ($/MWh)	Avoided Capacity Cost ($/kW)	Avoided Energy Cost ($/MWh)
2009	350	102	110	-	-	562	535	91.66	87.30	0.00	111.89
2010	350	105	114	-	-	568	516	92.70	84.08	0.00	121.46
2011	350	108	117	-	-	575	497	93.77	81.00	0.00	131.10
2012	350	111	121	-	-	582	479	94.87	78.05	0.00	133.40
2013	350	114	124	-	-	589	461	96.00	75.22	0.00	139.93
2014	350	118	128	-	-	596	445	97.17	72.51	160.34	146.48
2015	350	121	132	-	-	603	429	98.37	69.91	162.00	155.09
2016	350	125	136	-	-	611	413	99.61	67.42	160.15	159.54
2017	350	129	140	-	-	619	399	100.89	65.03	192.08	155.25
2018	350	133	144	-	-	627	385	102.20	62.74	192.80	164.57
2019	350	137	148	-	-	635	371	103.56	60.55	192.35	168.47
2020	350	141	153	-	-	644	358	104.95	58.44	183.14	166.80
2021	350	145	157	-	-	652	346	106.39	56.42	203.74	163.22
2022	350	149	162	-	-	661	334	107.87	54.48	200.11	168.86
2023	350	154	167	-	-	671	323	109.39	52.62	196.32	159.73

Levelized Bus-bar Cost, $/MWh	**98.83**
Net Levelized Cost ($1,000)	**606.04**
Levelized Avoided Capacity Cost, $/MWh	**14.11**
Levelized Avoided Energy Cost, $/MWh	**146.25**
Levelized Cost Premium, $/MWh	**(61.54)**

Figure 10-3. Kekaha Landfill Gas 15-Year Busbar Cost Calculation.

10.7 Advantages and Disadvantages of Technology

10.7.1 Fit to KIUC Needs

This landfill gas project is a good, but not ideal fit to KIUC's needs. It is a small amount of generation that is well-sized to be of value to KIUC. Further, the capacity of the system fits well with KIUC's current system needs.

10.7.2 Environmental Impact

The environmental benefit of this project would be twofold. The first benefit is preventing additional methane from escaping to the atmosphere. Methane is a potent greenhouse gas – 21 times more damaging than carbon dioxide. Capturing it and burning it in an engine or a flare reduces greenhouse gas emissions. Second, because the methane is not actively collected, there is potential that it could build up and cause an explosion in the future. Installing an LFG project would greatly reduce this possibility.

10.7.3 Socioeconomic Impact

This LFG project would have relatively minimal socioeconomic impact. It is not expected that more than one long term salaried position would be created by the project. Construction labor impacts will also be relatively low compared to the other renewable energy projects.

10.7.4 Incentives and Barriers

LFG projects have good appeal in terms of incentives and barriers. Generally, the public understands and accepts the technology as mature and environmentally positive. The project would be quick to implement with minimal planning, engineering and permitting compared to other technologies. KIUC already maintains staff who are knowledgeable of IC engine operations. There would be minor nuances to learn about burning LFG, but the transition would be straightforward. This project has previously been considered and studied, so there is already positive momentum toward implementing the project. Finally, the landfill owner seems willing to consider the project; this can be a significant hurdle for other projects.

There are no significant non-economic barriers perceived for this project.

10.8 Next Steps

The first step that should be taken to advance this project is to definitively understand what the closure date will be. As illustrated earlier, this will have a tremendous impact on the project gas production numbers.

Another early activity to pursue is obtaining and testing a gas sample from the existing landfill. Of primary importance are the lower heating value and gas contaminants. Unsatisfactory results could require additional capital expenditures for gas improvement equipment or modification of landfill operations.

After the gas sampling, the next two steps would be executing a Letter of Intent with the County to establish terms of the development. Execution of this document is a precursor to signing a gas transfer agreement with the County by which KIUC will be entitled to use the LFG. This is analogous to a PPA for landfill gas.

11.0 Final Renewable Energy Project Scoring

This section provides a brief discussion of the renewable energy project scoring methodology and the results of the scoring analysis. In general, the scoring approach is the same as that presented in Section 4. The major difference is that instead of scoring general technology types, the objective of this scoring process is to rank actual projects, which have been characterized in the previous sections. Only deviations from the previous screening approach will be presented in this section.

11.1 Objective

The objective of the project scoring methodology is to differentiate the many potential renewable energy projects by considering numerous factors affecting project viability including the cost of energy, resource availability, technology maturity, and environmental and socioeconomic impacts. The combination of each of these factors will provide an indication of the viability of a particular project and a measure of the non-economic benefits produced by each project.

The methodology used for the scoring analysis uses similar weighted criteria as were developed for the technology screening analysis in Section 4. Changes to the screening criteria are presented in the following section.

11.2 Scoring Criteria

The assessment methodology employs a set of seven criteria. The criteria are given different weights such that 100 total points are possible when the methodology is applied to a given project. Criteria are specific and measurable to ensure consistent evaluation and quantitative comparison of the final project scores. The seven criteria are summarized below:

- **Cost of energy** – Assesses the economic competitiveness of the resource. The evaluation is performed based on the levelized cost premium of generation. This is a measure of the life-cycle cost difference between generating power with the forecasted generation resource mix and the renewable energy project. This calculation considers the capital cost, fixed O&M, variable O&M, and project performance.
- **Kauai resource potential** – Assesses the potential generation from each renewable energy resource. This is also a measure of the replicability of a given project. The scores for this category are the same as those assigned in Section 4.

- **Fit to KIUC needs** – Assesses the fit of the project to the resource supply needs of KIUC. This criterion considers the scale of the project, typical generation profile, firm vs. as-available, etc.
- **Technology maturity** – Assesses the development status of the technology (commercial, demonstration, R&D, etc.) and the level of technical risk associated with its implementation.
- **Environmental impact** – Assesses the overall environmental impact of the project. Even among projects utilizing the same technologies, there are differences in the environmental impact. For example, the Upper Lihue hydro project has practical zero negative environmental impacts, whereas the Wailua hydro project has significant environmental impacts.
- **Socioeconomic impact** – Assesses the overall socioeconomic impact of the project. Includes factors such as increased local employment (construction and O&M), development of local resources, capacity building, and safety and health impacts.
- **Incentives/Barriers** – Indicates the degree of incentives offered for the project and barriers against the development of the project. Incentives may include federal/state subsidies or ancillary benefits of the project, such as addressing solid waste disposal problems. Barriers may include public opposition and other impacts that would raise concerns about the development of the project.

The weighting factors and evaluation guidelines for the criteria are provided in Table 11-1. The Levelized Cost Premium accounts for 50 percent of the overall score, with the rest of the criteria contributing varying degrees to the remaining 50 percent. The assessment methodology was applied by assigning a score from 0 to 100 for each criteria and then applying the weighting factors. The weighted scores are summed to provide the overall project score. Each criterion is scored differently, for example the "cost of energy" and "Kauai resource potential" criteria are largely based on quantitative information. For the remainder of the factors, quantitative data is typically not available, and a qualitative score must be assigned based on available information.

Table 11-1. Screening Methodology Scoring Guidelines.

Criteria	Weight	Scoring Details
Levelized Cost Premium	50	100 = lowest levelized cost premium 0 = highest levelized cost premium Proportionately scored between lowest and highest projects
Kauai resource potential	10	100 = overall developable resource potential of 500 GWh/yr or more 0 = overall developable resource potential of 5 GWh/yr or less Proportionately scored between 500 and 5GWh/yr
Fit to KIUC needs	10	100 = project is of appropriate scale, energy production profile matches KIUC needs, and meets KIUC needs regarding dispatchability, capacity vs. energy, etc. 0 = project is too large or small, produces energy at unneeded times, and provides product (such as capacity) of little value. Proportionately scored between two extremes
Technology maturity	10	100 = established commercial technology that has been widely adopted. Technology is offered by multiple competitive vendors and fully warranted. 75 = established technology that has been used in several similar applications 50 = early commercial technology that has been successfully demonstrated 25 = emerging technology in the demonstration phase 10 = technology still in research and development 0 = technology concept
Environmental impact	7.5	Relative to other renewable energy projects: 100 = Minimal negative environmental impacts 50 = some environmental impacts 0 = substantial negative environmental impacts
Socioeconomic impact	7.5	Relative to other renewable energy projects: 100 = substantial socioeconomic benefits enhancing the island's economy, health, and general well-being 50 = some socioeconomic benefits (base score) 0 = very little or negative socioeconomic effects
Incentives/ Barriers	5	100 = Significant incentives (e.g., project is in advanced state of development) and no apparent barriers to development. 50 = No significant incentives or barriers 0 = No incentives but substantial obstacles to successful project development

11.3 Scoring Results

The scoring methodology was applied to each candidate project, the results of which are presented below.

11.3.1 Levelized Cost Premium

The levelized cost premium of generating power from each of the projects was calculated. This value represents the cost of generating power with the renewable energy project above (or below) the cost of generating power with the default KIUC energy mix. The levelized cost premium is calculated by subtracting the avoided energy and capacity cost from the levelized busbar cost for each project.

Figure 11-1 and Figure 11-2 show supply curves of the amount of renewable energy generation available against the levelized cost and levelized cost premium, respectively. The curve was constructed by plotting the annual generation from each project against the levelized cost premium in ascending order. This represents the amount of renewable energy that can be generated below a given price. The chart shows the base fuel cost cases for each biomass and MSW option. An important conclusion from the supply curve is that about 400 GWh of renewable energy projects were identified by this study at a cost below KIUC's current avoided costs. KIUC generated about 430 GWh in 2003, largely from fossil fuel resources.

The results of the levelized cost premium analysis are provided in Table 11-2. Each of the projects identified utilize technologies that are fully commercial and are capable of producing power at prices competitive with conventional power plants. Further, compared to KIUC's forecasted avoided costs, all of the projects except the biomass plant produce power at a negative premium (savings). Generally, the least expensive power was found to be produced by the hydro and wind projects followed by MSW and biomass. The low power production cost from these resources can be attributed to good capacity factors, lower capital costs, and relatively low annual operating costs compared to the other projects.

Another observation than can be made from Table 11-2 is that projects developed under a KIUC ownership structure have a consistently lower levelized cost than projects constructed under developer ownership. This clearly shows that the low cost financing available to KIUC is able to overcome the federal and state economic incentives that private developers receive. However, there may be innovative public-private partnerships that could leverage KIUC's access to low cost financing with the tax credits available to private entities. Such arrangements could ultimately result in the lowest cost projects for KIUC.

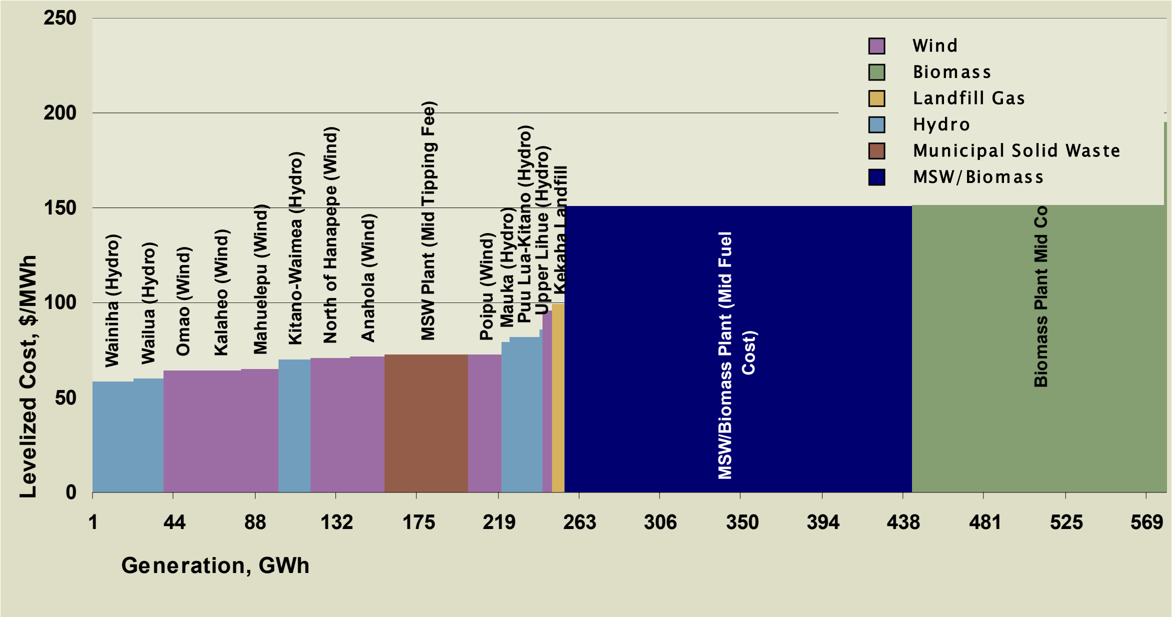

Figure 11-1. Levelized Cost Supply Curve (KIUC Ownership).

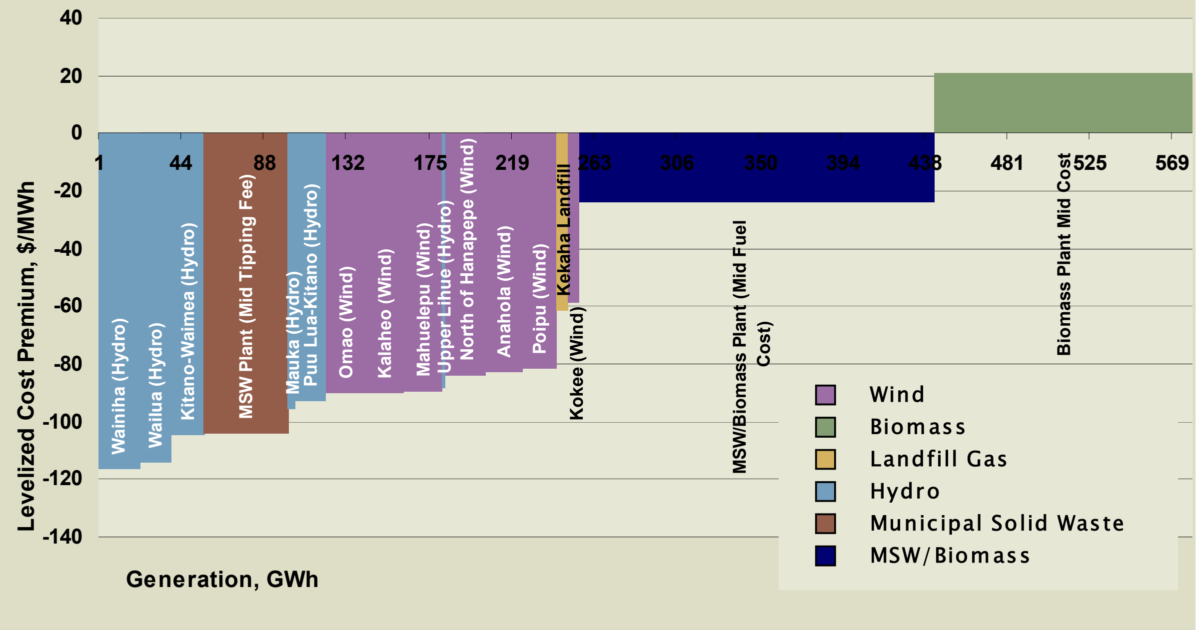

Figure 11-2. Levelized Cost Premium Supply Curve (KIUC Ownership).

Table 11-2. Project Performance and Cost Comparison.

	Net Plant Capacity, MW	Capacity Factor	KIUC Levelized Cost, $/MWh	KIUC Levelized Cost Premium, $/MWh	Developer Levelized Cost, $/MWh	Developer Levelized Cost Premium, $/MWh	Levelized Cost Premium Score
Hydro: Wainiha	4.0	64%	58.44	(116.30)	123.88	(50.86)	79
Hydro: Upper Lihue	0.3	69%	86.10	(88.64)	181.53	6.79	64
Hydro: Wailua	6.6	28%	60.38	(114.36)	127.57	(47.17)	78
Hydro: Waimea Mauka	2.9	15%	79.07	(95.67)	146.03	(28.72)	68
Hydro: Puu Lua-Kitano	3.0	61%	81.79	(92.96)	169.18	(5.56)	66
Hydro: Kitano-Waimea	4.1	48%	69.94	(104.81)	142.98	(31.76)	72
Wind: Kalaheo	6.6	35%	64.46	(90.10)	75.58	(78.98)	65
Wind: Omao	6.6	36%	64.24	(90.32)	75.70	(78.86)	65
Wind: North of Hanapepe	6.6	36%	70.76	(83.80)	86.55	(68.01)	61
Wind: Kokee	2.0	36%	95.88	(58.68)	112.12	(42.44)	48
Wind: Anahola	6.6	34%	71.68	(82.88)	87.05	(67.51)	61
Wind: Poipu	6.6	31%	72.77	(81.79)	87.12	(67.44)	60
Wind: Maha'ulepu	6.6	36%	64.24	(90.32)	75.70	(78.86)	65
Landfill Gas: Kekaha	0.8	86%	98.83	(61.54)	119.96	(40.40)	49
Biomass: Low Fuel Cost	20.0	80%	179.52	5.62	202.85	28.95	13
Biomass: Mid Fuel Cost	20.0	80%	194.77	20.87	216.96	43.06	5
Biomass: High Fuel Cost	20.0	80%	204.63	30.73	226.08	52.18	-
MSW: Low Tipping Fee	7.3	70%	108.66	(68.00)	212.83	36.17	53
MSW: Mid Tipping Fee	7.3	70%	72.38	(104.28)	179.26	2.60	72
MSW: High Tipping Fee	7.3	70%	20.39	(156.27)	131.16	(45.50)	100
MSW/Biomass: High Fuel Cost	27.8	77%	165.99	(8.66)	199.56	24.91	21
MSW/Biomass: Mid Fuel Cost	27.8	77%	150.72	(23.93)	185.43	10.78	29
MSW/Biomass: Low Fuel Cost	27.8	77%	125.45	(49.21)	162.05	(12.60)	43

11.3.2 Kauai Resource Potential

The near and long-term generation potential for each renewable resource was estimated in Section 4.3.2. The long-term (20-year) potential score is being used for this evaluation (refer to Table 4-5). Due diligence of each of the identified projects has been performed to assure that an adequate resource exists to support production. The long-term resource score is a measure of the replicability of each project type. In general, the greater the replicability of a project type, the better for KIUC. When multiple projects can be developed, lessons learned can be applied to future projects, savings in operation costs can be realized with multiple facilities, and improved performance may be realized through greater experience.

11.3.3 Fit to KIUC Needs

The Fit to KIUC Needs criterion is a measure of the applicability and suitability of a project to the KIUC system. During the screening analysis in Section 4, a score for each renewable resource was developed based on typical production profiles, dispatchability, and typical project size. Scores were developed for the next 3-years, 5-years, 10-years, and 20-years. Additionally, broad assumptions about the application of each technology were required to generate the initial score, which do not necessarily apply to individual projects. It is assumed that each of the projects identified for the Phase II analysis would be developed within the next 5 years, thus the scores from the 5-year time frame were used as the base for this analysis. Modifications to these base scores were made according to individual project characteristics and are presented in Table 11-3.

For the majority of projects, the general technology score was left unchanged for the individual projects. The Upper Lihue hydro upgrade project received a higher score because this facility is currently owned by KIUC, and the modifications are relatively minor in comparison to a new facility. The Kokee wind project received a higher score than the other wind projects because this option is smaller, could be implemented with little risk, and could be used to build KIUC experience with wind power generation. The biomass plant score was downgraded because of the scale of this project (too large?). Significant capacity is not needed on the KIUC system in the near-term, thus this project is less desirable. The same reasoning holds for the MSW/Biomass project. This is a large and complicated project whose capacity is not needed on the system for many years.

Table 11-3. Fit to KIUC Needs Scoring Results.

Project	Score	Comments
Hydro: Wainiha	75	Same as general technology score
Hydro: Upper Lihue	100	KIUC owned asset that could be easily upgraded
Hydro: Wailua	75	Same as general technology score
Hydro: Waimea Mauka	75	Same as general technology score
Hydro: Puu Lua-Kitano	75	Same as general technology score
Hydro: Kitano-Waimea	75	Same as general technology score
Wind: Kalaheo	75	Same as general technology score
Wind: Omao	75	Same as general technology score
Wind: North of Hanapepe	75	Same as general technology score
Wind: Kokee	85	Small project that could be demonstrated with little risk
Wind: Anahola	75	Same as general technology score
Wind: Poipu	75	Same as general technology score
Wind: Maha'ulepu	75	Same as general technology score
Landfill Gas: Kekaha	75	Same as general technology score
Biomass: Low Fuel Cost	37.5	Relatively large for near-term needs
Biomass: Mid Fuel Cost	37.5	Relatively large for near-term needs
Biomass: High Fuel Cost	37.5	Relatively large for near-term needs
MSW: Low Tipping Fee	50	Same as general technology score
MSW: Mid Tipping Fee	50	Same as general technology score
MSW: High Tipping Fee	50	Same as general technology score
MSW/Biomass: High Fuel Cost	25	Large complicated project
MSW/Biomass: Mid Fuel Cost	25	Large complicated project
MSW/Biomass: Low Fuel Cost	25	Large complicated project

11.3.4 Technology Maturity

All of the projects selected for the Phase II analysis utilize fully commercial technologies; therefore all of the projects received a score of 100 for this criterion. For a complete discussion of the technology maturity analysis refer to Section 4.1.4.

11.3.5 Environmental Impact

Previously, an assessment of the environmental and socioeconomic impact of each renewable energy resource was compared against the other renewable energy resources. For this analysis, differences between individual projects were highlighted to construct a unique score for each project. Projects with minimal negative impacts receive a 100, while those with potentially large impacts received a zero. Table 11-4 shows the results of the environmental impact scoring.

Table 11-4. Environmental Scoring Results.

Project	Score	Comments
Hydro: Wainiha	50	Issues to address, but no fatal flaws. Already an existing project on this stream. Land is all controlled by one private owner (A&B)
Hydro: Upper Lihue	100	Upgraded turbine, no incremental environmental impacts
Hydro: Wailua	25	Substantial diversion of Wailua river
Hydro: Waimea Mauka	85	Upgraded project with some slight disturbances of local environment
Hydro: Puu Lua-Kitano	40	Run of ditch project, minimal environmental impact. State and HI Home Lands
Hydro: Kitano-Waimea	40	Run of ditch project, minimal environmental impact. State and HI Home Lands
Wind: Kalaheo	75	Same as general technology score
Wind: Omao	75	Same as general technology score
Wind: North of Hanapepe	65	Would require construction of new road with associated impacts
Wind: Kokee	50	Located in protected area (state park, forest, etc.)
Wind: Anahola	40	Located in protected area (state park, forest, etc.), would require construction of new road with associated impacts
Wind: Poipu	75	Same as general technology score
Wind: Maha'ulepu	75	Same as general technology score
Landfill Gas: Kekaha	50	Same as general technology score
Biomass: Low Fuel Cost	50	Same as general technology score
Biomass: Mid Fuel Cost	50	Same as general technology score
Biomass: High Fuel Cost	50	Same as general technology score
MSW: Low Tipping Fee	25	Same as general technology score
MSW: Mid Tipping Fee	25	Same as general technology score
MSW: High Tipping Fee	25	Same as general technology score
MSW/Biomass: High Fuel Cost	25	Similar impacts as MSW plant
MSW/Biomass: Mid Fuel Cost	25	Similar impacts as MSW plant
MSW/Biomass: Low Fuel Cost	25	Similar impacts as MSW plant

For the most part, the wind, biomass, and MSW projects received the same environmental impact score as the general resource in the Phase I analysis. The Kokee and Anahola wind projects are located in protected areas, thus received a lower score than in the previous analysis. Significant changes were made to the scores for the hydro projects to account for the site specific nature of environmental concerns associated with hydro development, as noted in the table above.

11.3.6 Socioeconomic Impact

Each renewable energy technology was evaluated for socioeconomic benefits in the Phase I screening based upon criteria including job creation, solving existing socioeconomic problems, and transfer of knowledge. For this Phase II scoring effort, the socioeconomic scores from Phase I were re-examined for each specific project. The results of the socioeconomic scoring are provided in Table 11-5.

Table 11-5. Socioeconomic Scoring Results.

Project	Score	O&M employment	Construction employment	Other notes
Hydro: Wainiha	50	Low	Moderate	Improved/new road to site
Hydro: Upper Lihue	0	None	Very Low	
Hydro: Wailua	50	Low	Moderate	
Hydro: Waimea Mauka	12.5	Very Low	Low	
Hydro: Puu Lua-Kitano	55	Low	Moderate	Possible irrigation system benefits
Hydro: Kitano-Waimea	55	Low	Moderate	Possible irrigation system benefits
Wind: Kalaheo	25	Low	Low	
Wind: Omao	25	Low	Low	
Wind: North of Hanapepe	25	Low	Low	
Wind: Kokee	20	Low	Low	Slightly smaller project
Wind: Anahola	25	Low	Low	
Wind: Poipu	25	Low	Low	
Wind: Maha'ulepu	25	Low	Low	
Landfill Gas: Kekaha	25	Low	Low	
Biomass: Low Fuel Cost	80	High	High	Supports new agricultural crop
Biomass: Mid Fuel Cost	90	High	High	Highly supports new agricultural crop
Biomass: High Fuel Cost	100	High	High	Very highly supports new agricultural crop
MSW: Low Tipping Fee	85	High	High	Infrastructure benefits due to low cost waste disposal
MSW: Mid Tipping Fee	75	High	High	Infrastructure benefits due to waste disposal
MSW: High Tipping Fee	65	High	High	Infrastructure benefits due to waste disposal, but at high cost
MSW/Biomass: High Fuel Cost	100	High	High	Combined benefits of biomass and MSW
MSW/Biomass: Mid Fuel Cost	100	High	High	Combined benefits of biomass and MSW
MSW/Biomass: Low Fuel Cost	100	High	High	Combined benefits of biomass and MSW

The wind energy projects all received scores of 20-25, depending on size, based upon the anticipated employment impacts of the development of these projects. Even if all of the proposed wind generation were constructed, only a small O&M team would be required to service all of the turbines. Additionally, there would be little economic impact from construction due to the relatively short construction time of a wind energy facility and most of the materials being imported from outside the state.

The hydro projects received varying scores depending upon the scope of construction and new operations and maintenance personnel required. The Upper Lihue and Waimea Mauka projects received scores of zero and 12.5, respectively, because these are upgrade projects with limited construction scope and impact to operations and maintenance personnel. The Wainiha, Wailua, Puu Lua-Kitano, and Kitano-Waimea projects received scores between 50 and 55 largely due to the more expansive scope of construction

The biomass and MSW projects received scores ranging from 65 to 100, depending on the scope of employment and other economic benefits of the projects. The biomass project scores varied based on the level of support for new agricultural crops, which would depend on the price for biomass fuel. The MSW project scores varied with the tradeoff between waste disposal benefits and the cost for waste disposal. All MSW/Biomass plant price scenarios received a score of 100 due to the combined benefits of supporting agriculture and solving a waste disposal problem.

11.3.7 Incentives / Barriers

The degree of incentives and barriers for each renewable energy resource was characterized in the Phase I screening. These scores reflected the relative level of incentives and barriers for each technology type. The incentives or barriers to development used in the Phase I screening were modified to include more project specific criteria (project in active development, located near load centers, etc.), and the expanded set of criteria is presented in Table 11-6.

Table 11-6. Incentives / Barriers Scoring Criteria.

Points	Incentives	Points	Barriers
1	Complementary to Industry	1	Public Health Impacts
2	Good Public Acceptance of Technology	3	Negative Public Perception
2	Addresses Waste Disposal	2	Moderate Visual Impacts
2	Easily Actionable	4	Strong Visual Impacts
1	Replicability/Modularity	2	Potential Interference with Tourism
2	Experienced O&M Staff	2	Additional Infrastructure Required
2	Already in Active Development	2	Industry Supporting Infrastructure
2	Receptive Host Community/Land Owner	2	Hurricane Susceptible
2	Local Development Partners		
2	Near Island Load Centers		

The Phase I incentives/barriers scores have been re-examined and adjusted for the new criteria. The results are presented in Table 11-7. Differences were observed across all technology and project types. Overall, the hydro projects scored higher in the new analysis because of the inclusion of additional benefits related to project development activities. The wind projects generally scored lower than in the first analysis because of the inclusion of additional criteria related to visual impacts. The biomass and MSW projects scored similar to the initial screening analysis. Concerns over these technologies are related to negative public perception and possible health impacts.

11.3.8 Summary

The weighting factors were applied to each of the scoring criteria and were summed to produce a final score. A breakdown of the scores by criteria is in Figure 11-3. The figure shows that with the exception of the standalone MSW project with high tipping fees, the top ten ranked projects are all hydro and wind projects. The highest scoring project is the MSW project with high tipping fees. This project benefits greatly from its very low levelized power cost, about $20/MWh. The economics of the project are dependent high revenue from tipping fees, which may not be practicable. The Wainiha hydro project, which had been actively developed in the 1980s, is the second highest scoring project. It has a good combination of low power cost and high scores in most other categories, representing a solid project with few potential drawbacks. The next three projects (Omao, Kalaheo, and Maha'ulepu) are all wind and scored very similar. Of these projects, the Kalaheo site may be easiest to develop due to its large area, limited population and easy access. On the other end of the scale, the biomass and MSW/biomass plants were the lowest scoring projects, primarily due to higher costs of these projects. See the next section for additional discussion of these results.

Table 11-7. Incentives / Barriers Screening Results

	Incentives										Barriers								Score
	Complementary to Industry	Good Public Acceptance of Tech.	Addresses Waste Disposal	Easily Actionable	Replicability / Modularity	Experienced O&M Staff	Already active development	Receptive host community / land	Local development partners	Near Island Load Centers	Public Health Impacts	Negative Public Perception	Moderate visual impacts	Strong visual impacts	Potential interference with tourism	Additional infrastructure req'd	Industry Supporting Infrastructure	Hurricane Susceptible	
Points	1	2	2	2	1	2	2	2	2	2	-1	-3	-2	-4	-2	-2	-2	-2	
Hydro: Wainiha					■	■		■		■						■			70
Hydro: Upper Lihue				■	■	■	■	■		■									94
Hydro: Wailua					■	■	■			■		■			■				58
Hydro: Waimea Mauka				■	■	■													70
Hydro: Puu Lua-Kitano					■	■										■			54
Hydro: Kitano-Waimea					■	■										■			54
Wind: Kalaheo		■			■								■				■	■	38
Wind: Omao		■			■					■				■			■	■	38
Wind: North of Hanapepe		■			■		■						■			■	■	■	38
Wind: Kokee		■			■									■	■		■	■	22
Wind: Anahola		■			■		■	■	■	■			■			■	■	■	62
Wind: Poipu		■			■					■				■	■		■	■	30
Wind: Maha'ulepu		■			■					■				■	■		■	■	30
Landfill Gas: Kekaha		■		■		■	■	■	■										98
Biomass: Low Fuel Cost	■	■				■		■	■			■							74
Biomass: Mid Fuel Cost	■	■				■		■	■			■							74
Biomass: High Fuel Cost	■	■				■		■	■			■							74
MSW: Low Tipping Fee			■			■	■	■	■		■	■							74
MSW: Mid Tipping Fee			■			■	■	■	■		■	■							74
MSW: High Tipping Fee			■			■	■	■	■		■	■							74
MSW/Biomass: High Fuel Cost			■			■		■	■		■	■							66
MSW/Biomass: Mid Fuel Cost			■			■		■	■		■	■							66
MSW/Biomass: Low Fuel Cost			■			■		■	■		■	■							66

Table 11-8. Scoring Results Breakdown.

	Levelized Cost Premium	Kauai Resource Potential	Fit to KIUC Needs	Technology Maturity	Environ-mental Impact	Socio-economic Impact	Incentives / Barriers	Total Weighted Score
Category Weight	50	10	10	10	7.5	7.5	5	
Hydro: Wainiha	79	36	75	100	50	50	70	71.41
Hydro: Upper Lihue	64	36	100	100	100	-	94	67.72
Hydro: Wailua	78	36	75	100	25	50	58	68.42
Hydro: Waimea Mauka	68	36	75	100	85	13	70	65.71
Hydro: Puu Lua-Kitano	66	36	75	100	40	55	54	64.00
Hydro: Kitano-Waimea	72	36	75	100	40	55	54	67.16
Wind: Kalaheo	65	98	75	100	75	25	38	69.01
Wind: Omao	65	98	75	100	75	25	38	69.07
Wind: North of Hanapepe	61	98	75	100	65	25	38	66.57
Wind: Kokee	48	98	85	100	50	20	22	58.56
Wind: Anahola	61	98	75	100	40	25	62	65.65
Wind: Poipu	60	98	75	100	75	25	30	66.39
Wind: Maha'ulepu	65	98	75	100	75	25	30	68.67
Landfill Gas: Kekaha	49	0	75	100	50	25	98	52.73
Biomass: Low Fuel Cost	13	100	38	100	50	80	74	43.91
Biomass: Mid Fuel Cost	5	100	38	100	50	90	74	40.59
Biomass: High Fuel Cost	-	100	38	100	50	100	74	38.70
MSW: Low Tipping Fee	53	12	50	100	25	85	74	54.55
MSW: Mid Tipping Fee	72	12	50	100	25	75	74	63.50
MSW: High Tipping Fee	100	12	50	100	25	65	74	76.65
MSW/Biomass: High Fuel Cost	21	100	25	100	25	100	66	45.71
MSW/Biomass: Mid Fuel Cost	29	100	25	100	25	100	66	49.79
MSW/Biomass: Low Fuel Cost	43	100	25	100	25	100	66	56.55

Table 11-9. Scoring Results Breakdown (SORTED by Total Score).

	Levelized Cost Premium	Kauai Resource Potential	Fit to KIUC Needs	Technology Maturity	Environ-mental Impact	Socio-economic Impact	Incentives / Barriers	Total Weighted Score
Category Weight	50	10	10	10	7.5	7.5	5	
MSW: High Tipping Fee	100	12	50	100	25	65	74	76.65
Hydro: Wainiha	79	36	75	100	50	50	70	71.41
Wind: Omao	65	98	75	100	75	25	38	69.07
Wind: Kalaheo	65	98	75	100	75	25	38	69.01
Wind: Maha'ulepu	65	98	75	100	75	25	30	68.67
Hydro: Wailua	78	36	75	100	25	50	58	68.42
Hydro: Upper Lihue	64	36	100	100	100	0	94	67.72
Hydro: Kitano-Waimea	72	36	75	100	40	55	54	67.16
Wind: North of Hanapepe	61	98	75	100	65	25	38	66.57
Wind: Poipu	60	98	75	100	75	25	30	66.39
Hydro: Waimea Mauka	68	36	75	100	85	13	70	65.71
Wind: Anahola	61	98	75	100	40	25	62	65.65
Hydro: Puu Lua-Kitano	66	36	75	100	40	55	54	64
MSW: Mid Tipping Fee	72	12	50	100	25	75	74	63.5
Wind: Kokee	48	98	85	100	50	20	22	58.56
MSW/Biomass: Low Fuel Cost	43	100	25	100	25	100	66	56.55
MSW: Low Tipping Fee	53	12	50	100	25	85	74	54.55
Landfill Gas: Kekaha	49	0	75	100	50	25	98	52.73
MSW/Biomass: Mid Fuel Cost	29	100	25	100	25	100	66	49.79
MSW/Biomass: High Fuel Cost	21	100	25	100	25	100	66	45.71
Biomass: Low Fuel Cost	13	100	38	100	50	80	74	43.91
Biomass: Mid Fuel Cost	5	100	38	100	50	90	74	40.59
Biomass: High Fuel Cost	0	100	38	100	50	100	74	38.7

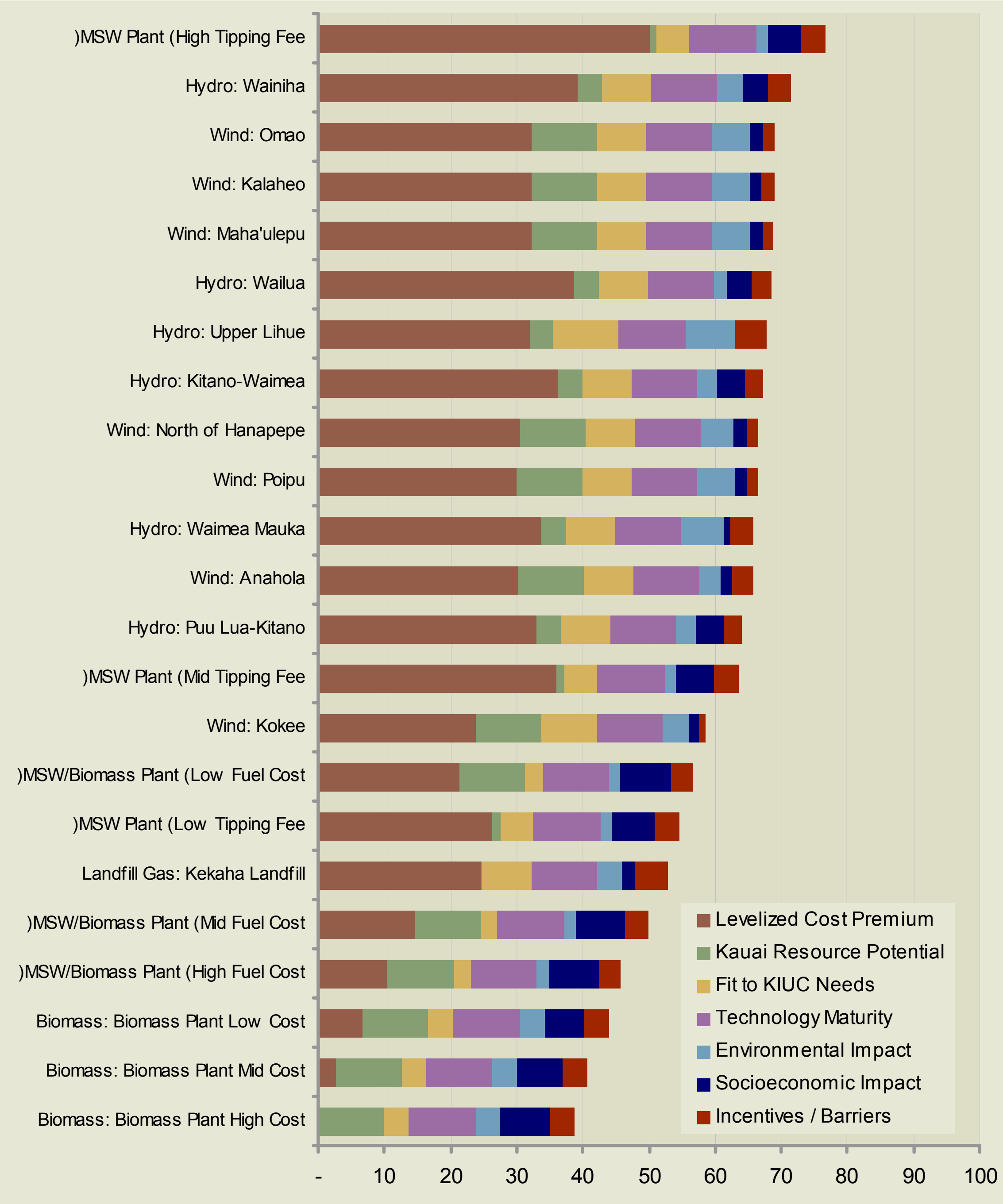

Figure 11-3. Scoring Results Breakdown.

12.0 Conclusions

The objective of this study is to identify the best renewable energy options for development on the island of Kauai. This project surveyed the renewable resources of Kauai and found that there are several commercial renewable energy resources that could reduce or eliminate Kauai's dependence on fossil fuels for electricity production. Further, it appears that developing these indigenous resources may be possible at lower cost than the present reliance on imported fuels.

This project reviewed the prospects for twenty six renewable and advanced energy technologies. After a first phase of screening, it was found that in the near-term, biomass, municipal solid waste, hydro, wind and landfill gas were the most promising options. Each of these technologies was assessed, typical projects characterized, and their economics evaluated. The summary conclusions of these assessments are provided here, in order of the most promising resources to least.

- **Hydro** – Out of over 40 options, six promising hydro projects were identified, and all seem very economical except for, perhaps, the Upper Lihue upgrade project. The lowest cost projects are the new 4 MW Wainiha and 6.6 MW Wailua developments, at levelized costs of $58.40/MWh and $60.40/MWh (2009$), respectively. However, hydro development does have challenges on Kauai. The last new utility scale hydropower plant on Kauai, Waimea Mauka, was constructed a half century ago. The reasons for this are varied, and highlight the importance of careful project selection, a measured development strategy, and a collaborative development approach involving agricultural/industrial partners, environmental advocates, and the greater island community as a whole. The most important next steps for hydro are discussions with site owners, followed by additional site investigation and feasibility analysis.
- **Wind** – Wind resources on Kauai are good and distributed throughout the island. Theoretically, wind could meet all of Kauai's electrical energy needs if a means could be found to "firm-up" the resource with energy storage or other technologies. This study characterized seven wind sites in Kauai. The projects ranged from developments on relatively flat land with moderate wind speeds but easy site access, to exposed ridgeline developments with higher wind speeds but more difficult construction. The life-cycle economic analysis showed that these attributes roughly counteract each other. With the exception of the smaller 2 MW Kokee project, the 6.6 MW wind projects were close in levelized cost, ranging from $64/MWh to $73/MWh. No wind

site stands out as being vastly superior to others, which gives KIUC good flexibility (and negotiation position) in siting the first projects in the location deemed most suitable. Recommended next steps for wind development are preliminary siting based on discussions with land owners and detailed meteorological data collection at likely sites to establish wind speeds at turbine hub heights.

- **Municipal Solid Waste –** Municipal solid waste combustion may be a viable option for Kauai as part an integrated approach to island waste management. However, the economics of MSW strongly depend on the tipping fee received for waste disposal. This study found that at a tipping fee of $90/ton, a 7.3 MW, 300 ton per day waste to energy plant would produce power for a lower levelized cost than any of the other renewable energy options modeled: $20/MWh. However, economics are very sensitive to this tipping fee. At $56/ton (the current landfill gate fee) the levelized cost was estimated to be $108/MWh. Although this is still lower than KIUC's current avoided cost, it is not as competitive as the other renewable energy options. If KIUC is interested in exploring waste to energy further, it should discuss possible options with the County. The current landfill is running out of capacity, and new landfill capacity will need to be developed. This new landfill capacity will likely be developed at an all-in cost near the upper range of the tipping fees modeled in this study.
- **Landfill Gas** – There is currently only one viable landfill gas project on Kauai, located at the Kekaha landfill. Black & Veatch estimated that an 800 kW project using reciprocating engines could be developed after landfill closure in 2009. At $99/MWh, the levelized cost of the landfill gas project is competitive with KIUC's current avoided costs, but higher cost than several of the other project options. The project is also considered lower priority for KIUC due to the limited resource potential of LFG on the island and the relatively small project size.
- **Biomass** – Of the project options characterized in detail for this study, biomass has the most unfavorable economics. As the study progressed from the generic technology screening in Phase 1 to the detailed project characterizations in Phase 2, the estimated costs for biomass increased outside of initial expectations. The Phase 2 investigation found that the levelized cost of supplying power from a biomass fueled power station ranged from $180/MWh to $205/MWh, depending on the fuel cost. Biomass is hurt by KIUC's lack of need for baseload capacity. However, biomass, especially

derived from locally grown energy crops, does have several advantages over most other renewable energy options: (1) large amounts of baseload power could be produced from the available resource base, (2) growing and harvesting local energy crops would provide a large stimulus for Kauai's agricultural economy and help stem the loss of jobs in the sugar industry and (3) biomass crops for power may be synergistic with crops grown for ethanol fuel production. Based on these factors, it is recommended that biomass be reexamined in more detail when KIUC has greater need for capacity resources in the future.

One of the most tangible benefits of renewable energy to KIUC is lowering the exposure to rising and volatile energy prices. As a final analysis, Black & Veatch compared the levelized cost of renewable energy against KIUC's short-term avoided costs, Schedule Q. A relationship was derived showing the variation in Schedule Q rates versus cost of oil.[113]

Figure 12-1 shows a comparison of the cost to generate power from each of the renewable projects analyzed in Phase 2 versus KIUC Schedule Q rates. While Schedule Q rates fluctuate with oil prices, renewable energy costs are constant. The figure shows at what oil price points renewable energy is less or more expensive than diesel engine power generation. At an oil price of about $55/bbl, landfill gas, wind, hydro, and municipal solid waste combustion are all less expensive. However, over the range of oil prices examined for this analysis, biomass combustion is always more expensive with a lower bound of about $180/MWh. The average price for diesel oil over the past four years is approximately $45/bbl. At this price point, hydro, wind, and municipal solid waste combustion with mid to high tipping fees are less expensive than KIUC's Schedule Q rates.

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[113] Personal communication from Jeff Deren, KIUC, November 23, 2004.

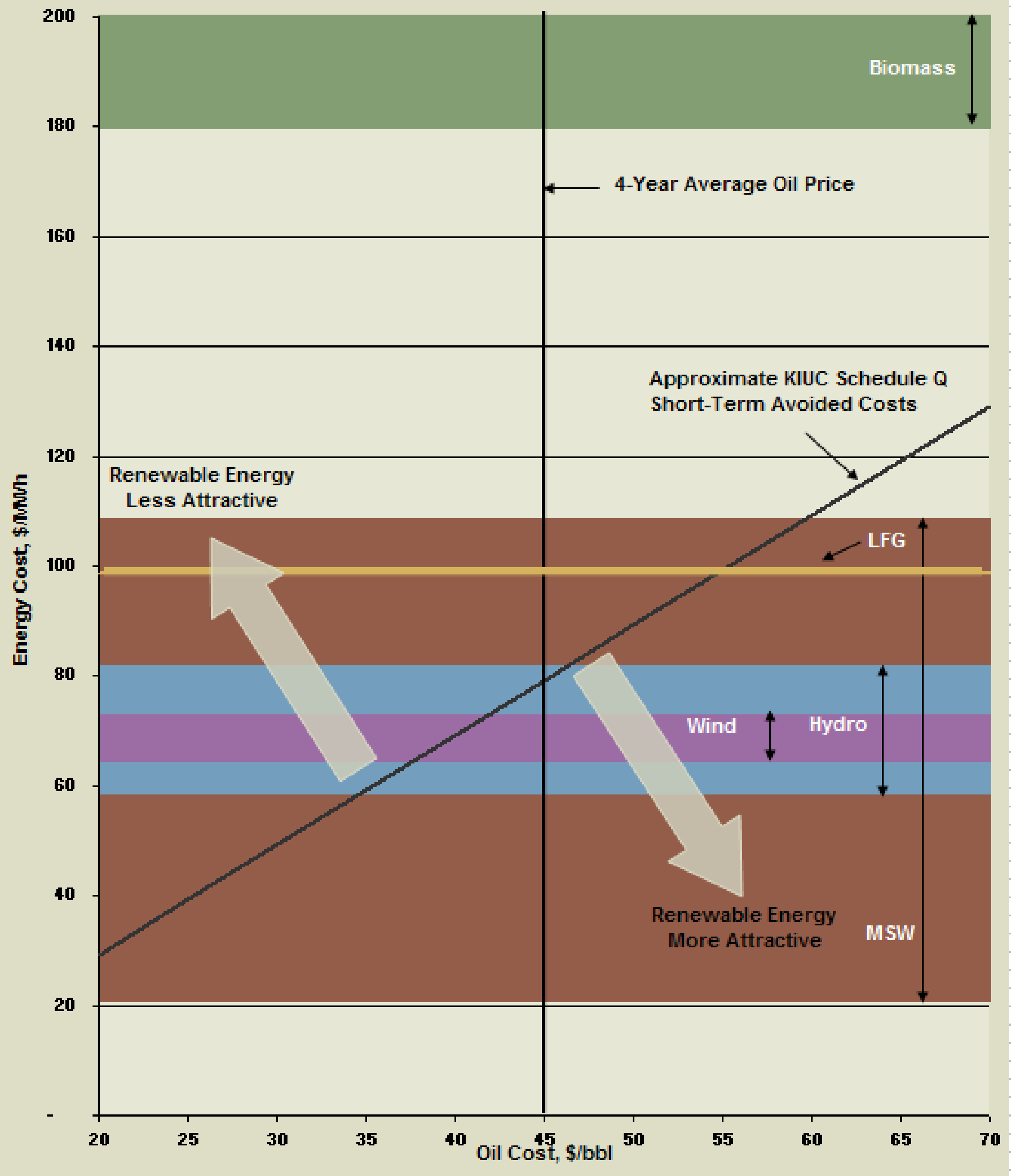

Figure 12-1. Break-Even Cost Analysis for Renewable vs. KIUC's Short Term Avoided Costs.

Appendix A. Hydro Prospects Identified

Region		Quad	River		Power	Conceptor		Corps	Report	Year	Forebay				Gravity Conveyance		Penstock		Powerplant		Afterbay		Head	Basin	USGS	Falls	Flow (cfs)			Size (kW)		Turbine		Plant	E (GWh/yr)		Const.	O&M
Project Name	Type	Sheet	Source	Owner	Purchaser	Name	Year	No.	No.*	Built	Name	Elev.	(feet)	(ac-ft)	Name	(feet)	(feet)	(inch)	Name	Elev.	Name	(ac-ft)	(feet)	(mi^2)	Gage	Name	Avg.	Prop.	Min.	Exst.	Prop.	No.	Type	Factor	Exst.	Prop.	($M)	($k/yr)
North																																						
Wainiha	run-of-river	Haena	Wainiha	Kaua'i Coffee	KIUC			E1	1,6,11	1906		699	20						Wainiha		-	-	564	13	16010800				0	3,800	?	4	Pelton		24	-	-	
Wainiha	run-of-river	Haena	Wainiha	Kaua'i Coffee	KIUC	McBryde	1985	-	11	-		1154	14				7,000	48		722	-	-	433		16108000	Puu Wainui	100	139	3	-	4,000	2	Pelton		-	22.5	$10.0	
Wainiha (1978)	run-of-river	Haena	Wainiha	Kaua'i Coffee		Corps	1978	-	8,14	-				0			6,800			0			189	10	16108000		143	31	3	-	430			90%	-	3.77	$6.0	$22
Wainiha (Hirai)	run-of-river	Haena	Wainiha	Kaua'i Coffee		Hirai	1981	-	8	-							7,000						290		16108000	Puu Wainui	139			-	3,700	2	1.6,2.1	54%	-	17.4	$6.1	
Kauai	storage		Wainiha	State of Hawai'i				-	6	-																				-	25,000				-	133.6	$59.6	
North	run-of-river		Lumahai	Garratt-Callahan				-	5, 6, 9	-																				-	6,000				-	32.1	$16.6	
Lumahei (1978)	run-of-river	Hanalei	Lumahei			Corps	1978	-	8,14	-													312		16106000			26	3	-	590			90%	-	1.5	$7.2	$32
Lumahai (1981)	run-of-river	Hanalei	Lumahai			Hirai	1981	-	8,13								11,400		Lumahai River				312		16106000	-	120			-	2,800	2	1.5, 1.3	57%	-	14.1	$6.2	
Hanalei (storage)	storage	Hanalei	Hanalei			Corps	1978	-	8,14	-				11,800			8,000						261					73	3	-	1,400			90%	-	12.3	$35.0	$58
Hanalei (1978)	run-of-river	Hanalei	Hanalei			Corps	1978	-	8,14														263		16103000			9	3	-	170			90%	-	5.17	$5.6	$23
Hanalei (1981, 1)	run-of-river	Hanalei	Hanalei			Corps	1981	-	8,13	-			10										263	10			104			-	4,500				-	16.5	$12.0	
Hanalei (1981, 2)	run-of-river	Hanalei	Hanalei			Hirai	1981	-	8	-							20,000						360		16101000		87			-	2,550			51%	-	11.5	$8.8	
Hanalei	run-of-river	Hanalei	Hanalei	Hanalei Hydro			80's	-	6, 8, 9	-																				-	6,000				-	2.9	$9.3	
Koloko	storage	Anahola	offstream	Mary N Lucas		Corps	1980	-	5,13	1890	Koloko	488	44	1,800	-	-								1		-	6			-	68				-	0.2		
Wehrheim's				John Wehrheim	n/a	Pacific Hydro		E8	5	1979																				?	-				?	-		
Namahana Farms						Pacific Hydro	2004	-																						-	3,500				-	?		
East																																						
Rancho Hydro	diversion		Anahola	John Harder				P3	5	-																				-	1.5				-	0.005	-	
Hanalei (Tunnel)	diversion		Hanalei			Hirai	1981	-	1,8	-					Hanalei Tunnel	6,028	8,000						510		16100000		27			-	1,400			67%	-	8.2	$3.7	
Upper Wailua	run-of-river		Hanalei	Island Power				-	6,9,11	-																			5	-	1,260				-	6.5	$2.5	
Wailua Reservoir (Above)	run-of-river	Kapaa	N. Fork Wailua	EKWUC		USBR	2004	-	2	-	Wailua			737	-	-	2,350	48			-		82			-		60	15	-	309	1	Francis		-	1.7	$3.0	
Wailua Reservoir (Below)	run-of-river	Kapaa	N. Fork Wailua	EKWUC		USBR	2004	-	2	-	Wailua			737	-	-	16,000	48			-		432			Kaholalele		60		-	1,629	1	Turgo		-	8.8	$11.7	
(Lower) Wailua	run-of-river	Kapaa	N. Fork Wailua	Symbiotics	KIUC	Symbiotics	2001	-	3-6,9,12,13	-	yes		28	430	-	-	4,800	96	Lower Wailua		-	-	262			Wailua	116	150	15	-	6,600	2	Francis		-	16.4	$13.1	$200
Wailua Ditch	run-of-ditch	Kapaa	N. Fork Wailua	EKWUC		USBR	2004	-	2	-	Wailua			737	Wailua Ditch											-				-	?				-	?		
Lateral 6	run-of-ditch	Kapaa	N. Fork Wailua	EKWUC		USBR	2004	-	2	-	Wailua			737	Lateral 6						Twin					-				-	?				-	?		
Upper Kapahi	storage	Kapaa	N. Fork Wailua	EKWUC		USBR	2004	-	2	-	Upper Kapahi			92							Twin					-				-	?				-	?		
Reservoir 21	storage	Kapaa	S. Fork Wailua	EKWUC		USBR	2004	-	10	-	Reservoir 21															-				-	?				-	?		
Aahoka	storage	Kapaa	S. Fork Wailua	EKWUC		USBR	2004	-	2	-	Aahoka																			-	?				-	?		
Upper Lihue (Waiahi)	run-of-river	Waialeale	S. Fork Wailua	JMB	KIUC	Pacific Hydro	2003	E6	1,2,4,5,8,10,13	1931					Illiliula Ditch		833	37	Upper Lihue	1050	-	-	247				27	32		500	800	1	Pelton		3.1	4.9	$2.0	
Lower Lihue (Waiahi)	run-of-river	Waialeale	S. Fork Wailua	JMB	KIUC	Pacific Hydro	2003	E7	1,2,5,8,13	1941					Illiliula Ditch		783	37	Lower Lihue		-	-	205		16068000		48			800	1,100	1	Francis		6.1	8.0	$1.6	
Wailua (Corps)	run-of-river		S. Fork Wailua	Lihue Plantation		Corps	1981	-	13	-			10	310									310	23	16060000	Wailua		150		-	8,400				-	18.7	$12.9	
Wailua (Hirai)	run-of-river		S. Fork Wailua	-	-	Hirai	1981	-	8	-							20,000						360	-	16060000	Wailua				-	11,700	2	3.2, 8.5	25%	-	25.2	$14.0	
Waialeale	storage		S. Fork Wailua	State of Hawai'i		BCA	1978	P2	5,8,13,14	-			185	22,700									559	18			57			-	9,200				-	50.0	$72.0	
Kapaia	storage		Hanamaulu	Lihue Plantation		Corps	1981	-	6,8,13	1910	Kapaia		45	1,114	-	-								2			10			-	120				-	0.18		
South																																						
Mauka Ditch	run-of-ditch	Koloa	Waihohonu	Hawaiian Mahogany		USBR	2004	-	6,11,13	1919	Puu O Hewa	580		123	Mauka Ditch				Malumalu				150			-	6			0	100				-	?		
Upper Alexander	storage	Koloa	Wahiawa	Kaua'i Coffee		USBR	2004	-	2,10	-	Alexander																			-	?				-	?		
Kalaheo	storage	Koloa	Wahiawa	Kaua'i Coffee	KIUC	Corps	1981	E5	1,8,13	1931	Alexander	1533	119	2,540		8,000	5,000		Kalaheo				699	3			7			1,000	1,000	1			2.1	2.1		
Alexander/Elua	pumped	Koloa	Wahiawa	Kaua'i Coffee		Hirai	1980	-	8	-	Alexander	1533	119	2,540		9,700				700	Elua		900							-	8,100				-	-14.4	$17.0	
Southwest																																						
Kaumakani	run-of-river	Waimea	Makaweli	Gay & Robinson	KIUC	Corps	1981	E4	3,8,13	1920			10						Kaumakani				211	5			10			1,250	1,250				3.1	11.4		
(Waimea) Mauka	run-of-river	Waimea	Waimea	ADC	KIUC	Corps	1981	E2	1,6,8-10	1954			10		Kekaha Ditch			42	(Waimea) Mauka	550			265	32	16031000			55		1,000	3,900				5.0	8.9	$3.2	
Waiawa	run-of-ditch	Kekaha	Kahoana	ADC	KIUC			E3	5,8	1907					Kekaha Ditch		1,000		Waiawa		-	-	280			-				500	700				1.9	4.0	n/a	
Kekaha-Waimea	run-of-river	Kekaha	Waimea	AMFAC Sugar		USBR	2004	-	2	-					Kekaha Ditch		1,850	36	Waimea (Makai)	30	-	-	430		16022000			60	22	-	1,700	1	Turgo		-	-	$3.3	
	run-of-ditch			Gay & Robinson		Vorfelt	2004	-	11	-		1000											800				116			-	5,000				-	?		
Koula Ditch	run-of-ditch			Gay & Robinson		Moe		-		-	-	600		0	Koula Ditch					0			600				108			-	?				-	?		
	storage	various	Kawaikoi	Gay & Robinson		Moe		-		-			20		Kokee Ditch												85	155	0	-	?				-	?		
Kokee (1964)	storage	various	Kawaikoi	AMFAC Sugar		DNLR	1964	P1	6, 8, 9	-	Kawaikoi	3400	240	36,215	Kokee Ditch	-			Puu Opae	2000	Puu Opae		1,400					8		-	10,000				-	53.4	$26.2	
Kokee (Corps)	run-of-ditch	Kekaha		AMFAC Sugar		Corps	1978	-	14	-					Kokee Ditch								982	1	16014000	-		6	0	-	430			90%	-			
Kitano (1st phase)	run-of-ditch	Kekaha	Haeleele	AMFAC Sugar		DNLR	1984	P4	5,6,8,9,13	1928	Kokee Ditch		110		-	-	9,100	24	Kitano	2123	Kitano	110	800		16014000		17	29	10	-	1,650	2	.7,.95	51%	-	8.0	$4.8	
Puu Opae (2nd phase)	run-of-ditch	Kekaha		AMFAC Sugar		DNLR	1984	P5	5,8	-	Kokee Ditch				-	-	13,700	24	Puu Opae	2000		31	1,030					12		-	700				-	?		
Mana Ridge (3rd phase)	run-of-ditch	Kekaha	Kawaikoi	AMFAC Sugar		DNLR	1984	P6	5,8	-	Kawaikoi	3400	182	18,412	-	-	16,000	30	Mana Ridge	2212	Mana Ridge	92	1,200					33	2	-	2,000	1	Pelton		-	10.7	$16.1	
Puu Lua-Kitano	run-of-ditch	Makaha	Kawaikoi	AMFAC Sugar		USBR	2004	-	2	-	Puu Lua	3268		798	-		29,716	36	Kitano	2123	Kitano	110	1,145		16014000	-	24	40		-	2,970	1	Pelton	60%	-	15.8	$17.6	$254
Kitano-Waimea	run-of-ditch	Kekaha		AMFAC Sugar		USBR	2004	-	2	-	Kitano	2123		110	-		26,400	30	Waimea Makai	30	-	-	2,093			-		30	10	-	4,078	1	Pelton	48%	-	17.1	$16.1	$233

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14. Summary Report for Hydroelectric Power, State of Hawaii, U.S. Army Corps of Engineers, Honolulu District, October 1978

Ownership Changes

McBryde Sugar = Alexander and Baldwin = Kaua'i Coffee
Olokele Sugar = C Bruir = Gay & Robinson
Kekaha Sugar (late 90's) = AMFAC = State of Hawaii = ADC
Lihue Plantation (2000) = AMFAC = JMB

🟦 Existing - Promising for upgrade
⬜ Existing - Not promising for upgrade
🟩 New - Promising projects