# 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.

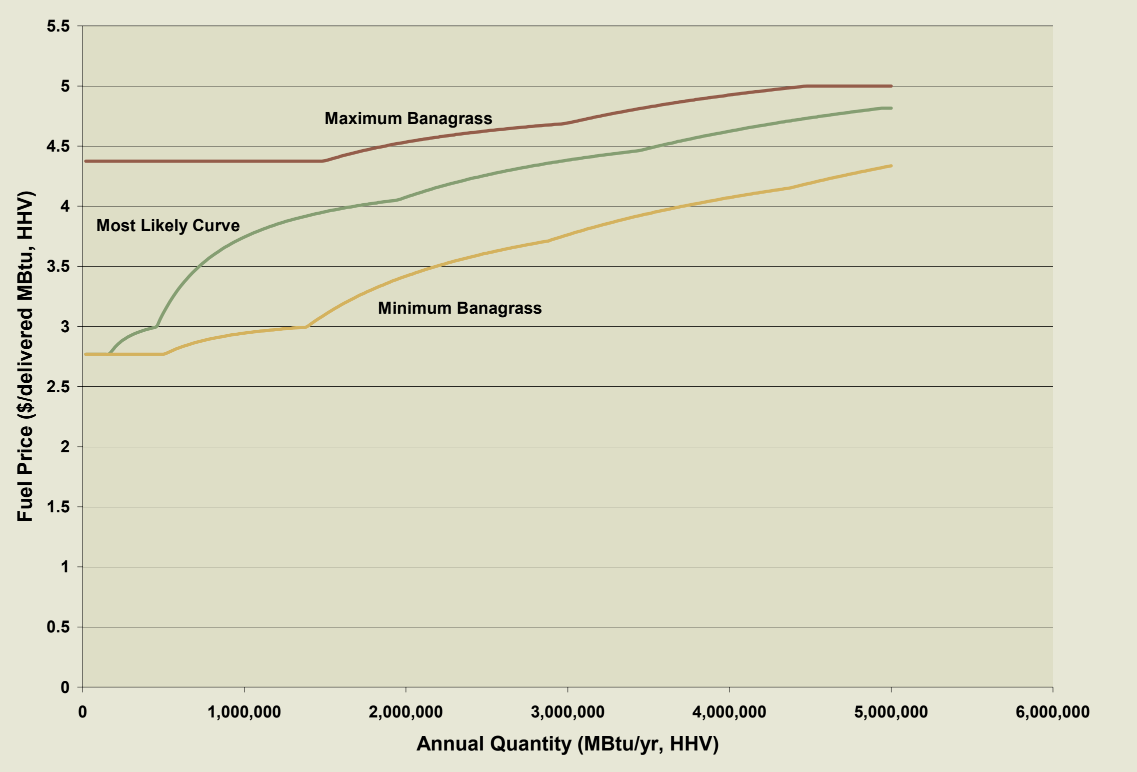

Figure 7-1 - Biomass Fuel Supply Curve

### *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.

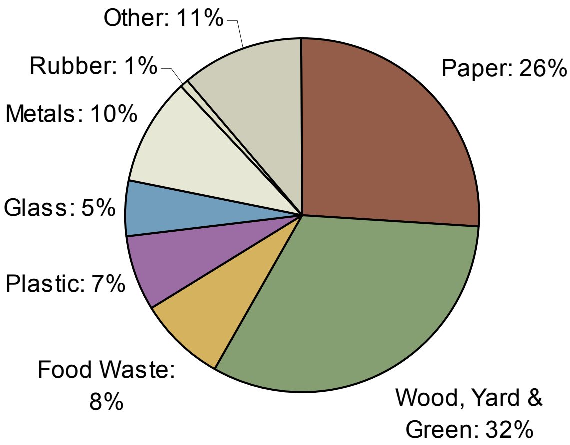

**Figure 7-2. Kauai MSW Composition.**

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.

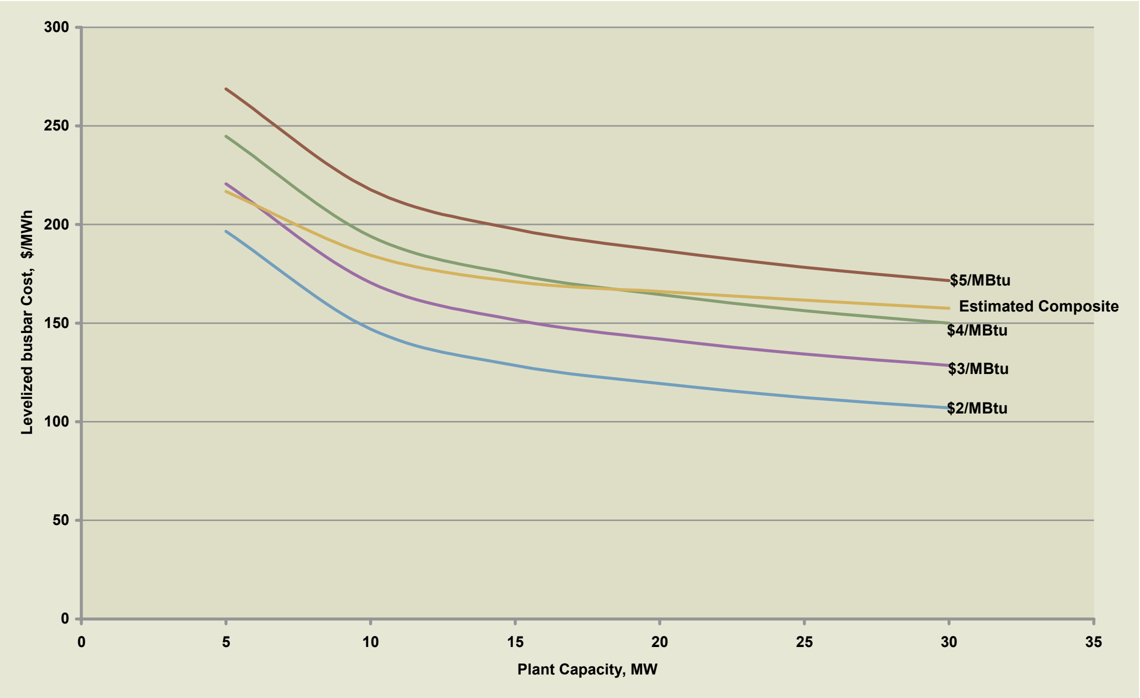

**Figure 7-3. Comparative Biomass Busbar Cost with Varying Fuel Price.**

### 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.

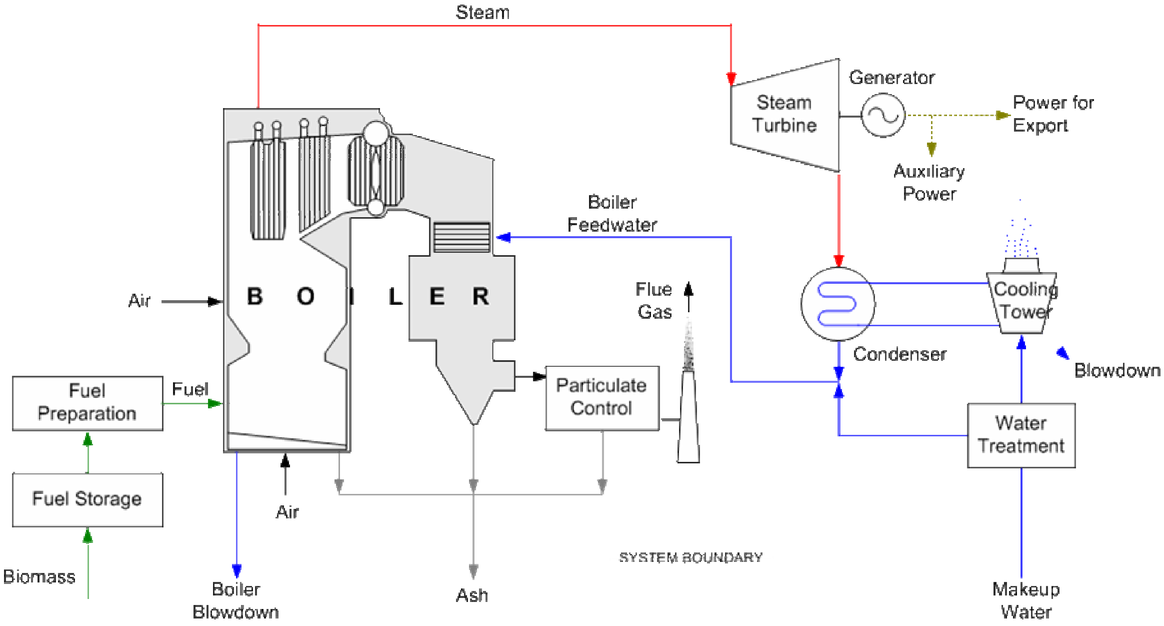

**Figure 7-5. Biomass Schematic**

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.

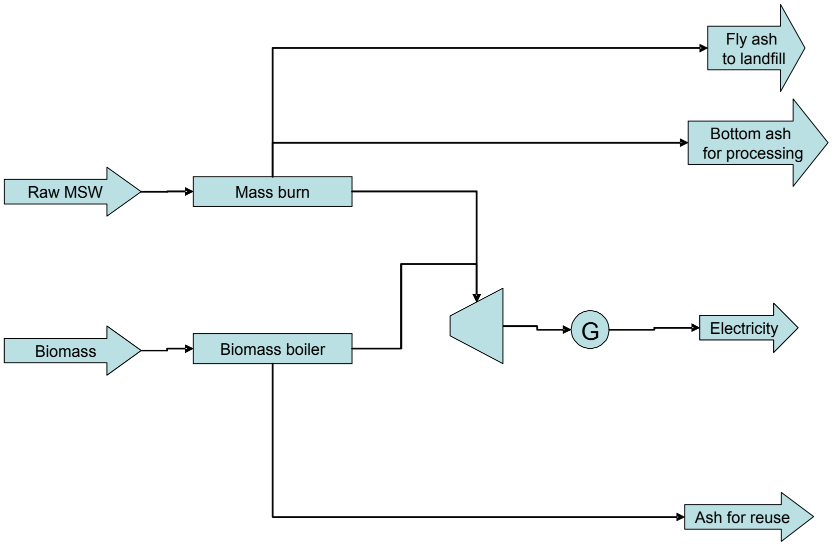

**Figure 7-6. Combined Biomass and MSW Schematic**

## 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 openfield 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.