# 10.1 Introduction

Anaerobic Digestion (AD) in the broadest sense is a process to degrade organic material in the absence of oxygen. Therefore, AD breaks down the organic fraction of waste. This includes paper, yard waste, food waste, and other organic wastes. The process of AD can be accelerated in landfills through the implementation of a bioreactor. However, this section focuses on "in vessel" AD. The following discussion will examine organic feedstocks, processes, products/byproducts, environmental issues, current facilities, and applicability to Kauai's waste stream.

Methane is emitted from anthropogenic sources such as agriculture (rice fields, animal breeding and fattening), combustion, and landfills. AD not only provides pollution prevention opportunities, but also produces reusable byproducts methane (i.e., medium Btu biogas) and digestate (i.e., fibrous byproduct and water). The process requires thermal energy to heat the digesters and electricity to operate the ancillary equipment, while engine-generators combust the biogas cogenerating electricity and thermal energy. Overall, AD is a net energy producer. The potential also exists for the reuse of the residual fiber as compost. The technology has been applied extensively to the management of biosolids. As the application of the technology continues to mature, AD is becoming a viable method for promoting waste reduction, energy recovery of biomass, and useable byproducts.

Worldwide, more than 130 large AD plants operate that digest the organic fraction of the municipal solid waste (OFMSW) stream and/or organic industrial wastes. All but approximately five of these installations are located in Europe. Various AD technologies are operational, including wet and dry digestion processes with single and multiple stages. No commercial-scale AD facilities are presently operating in the United States that use municipal solid waste or OFMSW as feedstocks.

Presented below is a discussion of the materials flow, technology, and planning assumptions we have made in evaluating the potential costs associated with an AD facility to serve the County. A wide variety of engineered systems have been specifically developed for the rapid "in vessel" digestion of the OFMSW and other types of organic wastes. Most systems operate in the thermophilic (122°F-131°F) state to accelerate performance. Each has its own special benefits and constraints. Although many hybrids exist, six basic types of AD systems reduce volume and recover energy from solid wastes. The basic types include: (1) wet single-step, (2) wet multi-step, (3) dry continuous, (4) dry sequencing batch, (5) dry one-step, and (6) percolation (dry two-step). Anaerobic digestion is operational at over 130 locations throughout Europe primarily to manage OFMSW, yard wastes, food wastes, organic

industrial wastes, sludges, and manures. The primary applications of the wet single-step systems are to co-digest source-separated OFMSW with a liquid substrate such as manure or sewage sludge. This system is not typically used for the AD of the full OFMSW stream. Generally, wet digestion is only economically feasible when the residual liquids can be reused. Contrastingly, the dry one- and two-step systems can usually manage OFMSW effectively. Considering the characteristics of the organic feedstock available in Kaua‘i, the dry one-step system with mechanical treatment was selected for this analysis due to the lower moisture content of the feedstock.

## 10.2 Material Flow

AD facilities generally use enclosed tipping floors to stockpile the OFMSW prior to processing. The life expectancy for AD facilities is generally 15 to 20 years. For purposes of this analysis, this option relied on the residential and commercial solid waste quantity projections through 2020 provided in Tables 4-5 and 4-15 in Section 4.3.B and adjusted the generation quantities based on the amount of each waste stream that the facility may receive[1]. The first year of operation for a new AD facility on Kaua‘i was set at 2011 to account for the projected timeframe needed for siting and project development. The analysis in Table 10-1.B uses the following assumptions:

- For the first 10 years (2011 – 2020) of operation, the multiple units of the AD facility will have sufficient processing capacity;
- For the second 10 years (2021 – 2030) of operation, potentially expand the AD facility to provide sufficient processing capacity;
- The AD facility will have a 90 percent availability factor due to scheduled and unscheduled equipment outages;
- The mechanical preprocessing system will mechanically remove 5 percent as unacceptable materials by weight for landfill disposal;
- After biological post-processing, the AD facility will produce 10 (minimum) to 20 (maximum) percent residue by weight from waste processed; and,
- The AD facility will minimize bypassing processable waste to the landfill for disposal.

The projected processable quantities and average daily processing capacities required by year are provided in Table 10-1.B

R. W. Beck selected facility sizes for the option analysis as follows:

1. For the first 10 years of operation, a 110-tpd AD facility will comprise multiple processing units. The annual facility processing capacity will be approximately 36,100 tons per year in 2011.

[1] R. W. Beck estimated that the facility would receive 90 percent of the residential green wastes generated and 50 percent of the residential food waste and non-recyclable, but compostable paper.

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Table 10-1
Projected Quantities for Anaerobic Digestion Facility

| Year | Green Waste Diverted (tpy) (1) | Residential Food Waste Diverted (tpy) (2) | Commercial Food Waste Diverted (tpy) (2) | Non-Recyclable Paper Diverted (tpy) (2) | Biosolids Diverted (tpy) (2) | Total Organic Fraction Received (tpy) (3) | Processable Quantity (tpy) (4) | Preprocess-ing Residue (tpy) (5) | Average Processing Capacity (tpd) (6) | Processed Quantity (tpy) (7) | Minimum Residue Quantity (tpy) (8) | Maximum Residue Quantity (tpy) (9) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2011 | 12,910 | 3,825 | 4,144 | 4,386 | 1,790 | 27,055 | 25,702 | 1,353 | 78 | 25,702 | 2,570 | 5,140 |
| 2012 | 13,130 | 3,998 | 4,331 | 4,579 | 1,869 | 27,906 | 26,511 | 1,395 | 81 | 26,511 | 2,651 | 5,302 |
| 2013 | 13,340 | 4,177 | 4,525 | 4,778 | 1,950 | 28,770 | 27,332 | 1,439 | 83 | 27,332 | 2,733 | 5,466 |
| 2014 | 13,580 | 4,367 | 4,731 | 4,990 | 2,037 | 29,705 | 28,219 | 1,485 | 86 | 28,219 | 2,822 | 5,644 |
| 2015 | 13,800 | 4,565 | 4,945 | 5,210 | 2,127 | 30,646 | 29,114 | 1,532 | 89 | 29,114 | 2,911 | 5,823 |
| 2016 | 14,040 | 4,770 | 5,167 | 5,438 | 2,220 | 31,634 | 30,052 | 1,582 | 91 | 30,052 | 3,005 | 6,010 |
| 2017 | 14,270 | 4,982 | 5,397 | 5,674 | 2,316 | 32,640 | 31,008 | 1,632 | 94 | 31,008 | 3,101 | 6,202 |
| 2018 | 14,500 | 5,203 | 5,636 | 5,919 | 2,416 | 33,674 | 31,990 | 1,684 | 97 | 31,990 | 3,199 | 6,398 |
| 2019 | 14,740 | 5,436 | 5,890 | 6,179 | 2,522 | 34,767 | 33,029 | 1,738 | 101 | 33,029 | 3,303 | 6,606 |
| 2020 | 15,000 | 5,684 | 6,158 | 6,455 | 2,635 | 35,932 | 34,135 | 1,797 | 104 | 34,135 | 3,414 | 6,827 |
| 2021 | 15,163 | 5,722 | 6,199 | 6,498 | 2,653 | 36,234 | 34,423 | 1,812 | 105 | 34,423 | 3,442 | 6,885 |
| 2022 | 15,385 | 5,905 | 6,397 | 6,702 | 2,736 | 37,125 | 35,269 | 1,856 | 107 | 35,269 | 3,527 | 7,054 |
| 2023 | 15,608 | 6,088 | 6,595 | 6,905 | 2,819 | 38,015 | 36,115 | 1,901 | 110 | 36,115 | 3,611 | 7,223 |
| 2024 | 15,831 | 6,270 | 6,793 | 7,109 | 2,902 | 38,906 | 36,960 | 1,945 | 113 | 36,960 | 3,696 | 7,392 |
| 2025 | 16,054 | 6,453 | 6,991 | 7,313 | 2,985 | 39,796 | 37,806 | 1,990 | 115 | 37,806 | 3,781 | 7,561 |
| 2026 | 16,277 | 6,636 | 7,189 | 7,516 | 3,068 | 40,687 | 38,652 | 2,034 | 118 | 38,652 | 3,865 | 7,730 |
| 2027 | 16,500 | 6,819 | 7,387 | 7,720 | 3,151 | 41,577 | 39,498 | 2,079 | 120 | 39,498 | 3,950 | 7,900 |
| 2028 | 16,723 | 7,002 | 7,585 | 7,924 | 3,235 | 42,468 | 40,344 | 2,123 | 123 | 40,344 | 4,034 | 8,069 |
| 2029 | 16,945 | 7,185 | 7,783 | 8,127 | 3,318 | 43,358 | 41,190 | 2,168 | 125 | 41,190 | 4,119 | 8,238 |
| 2030 | 17,168 | 7,367 | 7,981 | 8,331 | 3,401 | 44,249 | 42,036 | 2,212 | 128 | 42,036 | 4,204 | 8,407 |

(1) Green Waste Diverted in tons per year (tpy) is from Table 4-5 in Section 4B.
(2) Assumes 50% of Food Waste (Residential and Commercial), Non-Recyclable Paper, and Biosolids Diverted (wastewater treatment sludge) in tons per year per Table 4-15 in Section 4B. From Table 4-14, the Residential Food Waste and Commercial Food Waste Diverted are 48% and 52% of the total food waste by weight diverted.
(3) Total Organic Fraction Received is the sum of Green Waste, Residential Food Waste, Commercial Food Waste, Non-recyclable Paper, and Biosolids Diverted in tons per year.
(4) Processable Quantity in tons per year equals Total Organic Fraction Diverted less 5% Preprocessing Residue.
(5) Preprocessing Residue in tons per year is the Total Organic Fraction Received times 5%.
(6) Average Processing Capacity in tons per day equals Processable Quantity in tons per year divided by 365 days per year and 90% facility capacity availability.
(7) Processed Quantity is the Processable Quantity up to the rated facility processing capacity in tons per year times a 90% annual availability factor.
(8) Minimum Residue Quantity is the Processed Quantity in tons per year times 10%.
(9) Maximum Residue Quantity is the Processed Quantity in tons per year times 20%.

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2. For the second 10 years of operation, the AD facility could add another processing unit. The annual facility processing capacity will be approximately 55,800 tons per year by 2021.

If the diversion of the OFMSW is less than projections, the County may delay the addition of another processing unit at the AD facility.

### 10.2.1 Technology Overview

A 110-tpd AD facility will consist of a medium size building, including an enclosed waste receiving and storage area (includes adequate ventilation to address odors), digester area and ancillary equipment room, operations control center, utilities service area, biogas engine-generator area, and residue storage area. Windrow composting of the AD process residue will occur on a large concrete pad outdoors with storm water control. Odor control measures will be implemented such as a biofilter. The composted residue will require an on-site storage area for curing. Initially, the facility will include multiple digesters with available space to expand the waste receiving and storage enclosure, and potentially add another identical processing unit and biogas engine-generator.

The AD facility will be situated on a minimum 12- to 15-acre site surrounded by additional buffer area. The ideal selected site should exist near a major road for ease of access, water supply source, wastewater discharge point to treat wastewater, and electrical interconnection.

### 10.2.2 Applicability to the Waste Stream

Section 4B identified the following components as possible organic components for feedstock to the AD facility:

- Green waste
- Residential food waste
- Non-Recyclable, but compostable paper
- Biosolids (wastewater sludge)

In addition, commercial waste sources are expected to divert approximately 60 percent of their food waste to the AD facility.

Program experience in Europe and the United States has shown that comprehensive source separation of organics provides the best quality feedstock for either composting or AD, with a minimum of heavy metal and plastic contamination. Where source separation has been mandated in Europe, the results have been encouraging. The experience of some European communities indicates that 30-50 percent of the total OFMSW can be successfully collected and managed separately.

The most applicable characteristics of AD feedstock are used when the organic fraction can be collected at the source of generation, (e.g., food processing industries, pulp and paper mills, etc.). In addition to minimal contamination, the waste

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composition using this approach is more consistent over time for achieving steady biogas production. This is optimal for conversion into a useful energy byproduct.

As proposed in Section 4B, the County would provide wet-dry collection service to the residents. The haulers will deliver the wet or OFMSW to the AD facility. The facility will process the organic fraction with mechanical treatment to remove contaminants for landfill disposal. For purposes of this analysis, the AD facility will remove 5 percent contaminants by weight through mechanical preprocessing for landfill disposal. Even with source separation by waste generators. Some preprocessing will continue to be necessary.

### 10.2.3 Volume Reduction and Diversion Potential

AD facilities can result in an 80-90 percent volume reduction of the organic solid waste received. Potentially, mixed municipal solid waste could be received at AD facility and a "dirty" materials recovery facility (MRF) could be integrated into the facility to process the non-organics. However, this approach creates greater risks as it relates to the quality of the feedstock, directly impacts biogas production, increases the capital investment, and increases the quantities of residue. As a result, as an alternative, the proposed approach for Kauai County includes separation of these materials at the source. The "processable" quantities shown in Table 10.1.B reflect the latter approach, where organics would be separated at the source.

### 10.2.4 Environmental Considerations

As with other solid waste processes, the AD facility may emit fugitive dust (particulate matter) and odors associated with the materials handling components of the process. Depending on the extent of potential fugitive dust, proper industrial ventilation design and control with a baghouse may be required. Organic emissions and odors in material handling areas may also require local ventilation and control with activated carbon systems. Assuming that the process vents are completely leak-free, no air emissions or odor nuisances will occur from the AD process since it is fully enclosed. A scrubber will remove hydrogen sulfide and moisture directing the cleaned biogas (composed primarily of methane) to a low $NO_x$ reciprocating engine to cogenerate electricity and thermal energy to heat the digesters. Combustion of the biogas will result in emissions of nitrogen oxides ($NO_x$), carbon monoxide (CO), volatile organic compounds (VOC), particulate matter, and sulfur dioxide ($SO_2$).

The AD facility would have to meet the State's air quality requirements of Chapter 11-60.1 Hawai'i Administrative Rules (HAR), Subchapter 5 – Covered Sources. Relating to the State's solid waste regulations, the AD facility must comply with HAR Sections 11-58.1-32 Recycling and Materials Recovery Facilities and 11-58.1-41 Composting Facilities. The AD facility will require obtaining air quality and solid waste permits to construct and operate.

The AD process will produce some wastewater, which would need treatment and disposal. Proper process design and moisture management can minimize this byproduct to a negligible level or eliminate this stream. In some instances, the

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moisture resulting from the process has been treated and used for irrigation or reintroduced into the composting process for the residue.

## 10.3 Residuals

The coproducts of the AD process are a medium Btu content biogas and a slurry called digestate. The biogas contains approximately 50-70 percent methane and is water saturated. The balance of the biogas mixture is carbon dioxide, and some parts per million (ppm) of hydrogen sulfide. The digestate consists of undigested solids, cell mass, soluble nutrients, other inert materials, and water.

As previously discussed, for purposes of this analysis, an AD facility would process approximately 95 percent of the diverted organic wastes received by weight. The preprocessing system mechanically separates unacceptable material, which is disposed of at the landfill. The system would employ bag breaking and screening. Depending on the volatile content and quality of the feedstock, the AD facility will produce combined residue that is 10 to 20 percent by weight of the material processed. After the digestion process, the post-processing of the resulting residue will occur. The post-processing system includes mechanical dewatering followed by biological treatment by windrow composting outdoors for 10-15 days. The final product will be sold as soil conditioner. Table 10-1.B presents annual quantities of preprocessing and post-processing (minimum and maximum) residues by weight produced by the AD facility.

### 10.3.1 Planning Level Cost Estimate

The data in this document represent planning level cost estimates to determine a range of first-year tipping fees for the AD facility. This data is not intended for project financing and is intended for comparison to other alternative technologies. If the County decides to move forward with the development of the proposed AD facility, a more detailed analysis would need to be completed. For planning purposes, the implementation time required for the proposed facility is approximately five years.

The planning level cost estimate for the AD system uses the following assumptions:

- Waste Processing Capacity
  - 90 percent annual facility availability factor;
  - At 110 tpd rated capacity, the facility will process a maximum of 36,100 tons per year with the assumed availability factor;
  - In 2011, the facility will receive approximately 27,100 tons of materials and process approximately 25,700 tons of the OFMSW; and,
  - The approximate difference (1,400 tons) between OFMSW received and OFMSW processed will be landfill disposed at $70 per ton.
- Capital Cost. The estimated capital cost includes provision for the construction of the facility, excluding electrical interconnection. The 110-tpd facility would consist of multiple digesters. The estimate assumed the following components:

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- No direct costs for land for the facility site
- Waste receiving and storage – three days enclosed waste storage with odor control
- Preprocessing – minimal mechanical separation to remove unacceptable materials
- Digesters – operations control center, pumps, heaters, and other ancillary equipment
- Post-processing – mechanical dewatering, outdoor windrow composting on concrete pad, and storm water controls
- Biogas engine-generators – gas scrubbers, low $NO_X$ units, switchgear, auxiliary fuel oil handling and storage system, continuous monitoring system, and stack
- Capital "Hard" Cost – $320 to $390 per annual ton of installed capacity for approximately 40,200 tons (2011 dollars), which is equivalent to $12.8 to $15.7 million
- Project Development "Soft" Cost – 15 percent of the capital cost includes engineering, permitting, financing, air emission offsets, spare parts, start-up, and contingency, which is equivalent to $1.9 to $2.3 million

- Annual Debt Service Requirements
  - Financing costs of 2 percent of the principal amount of the bond issue
  - Interest rate on the bonds of 5 percent
  - Revenue bonds with 20 years of operation and a principal repayment period of 20 years
  - Level debt service payments for 20 years
- Operating & Maintenance (O&M) Expenses
  - The O&M expenses include provision for labor, parts and supplies, extraordinary renewals and replacements, general and administration, operator profit, electricity, fuel, and "normal" pass throughs such as chemicals, insurance, and utilities. This does not include property taxes, and host fees.
  - O&M Expenses – $40 to $45 per ton of solid waste processed (2011 dollars)
- Residue Disposal Expenses and Reuse Re
  - A mechanical preprocessing system will remove 5 percent residue (on a weight basis) of the solid waste received for landfill disposal. In 2011, the preprocessing system will remove approximately 1,400 tons of residue.
  - A biological post-processing system will produce 10-20 percent residue (on a weight basis) of the solid waste processed. Seventy-five percent of the compost may potentially sell as a soil conditioner at $10 per ton. The unsold

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material is used as alternative daily cover at the landfill. In 2011, the facility will generate approximately 2,600 to 5,100 tons of process residue.

- Electricity Production Capability and Revenues
  - Net electrical generation will range from 120-150 kWh per ton of waste processed.
  - In 2011, the facility will deliver the excess power to Kaua‘i Island Utility Cooperative (KIUC) at the energy charge of $0.131 per kWh. This value was obtained from the *Renewable Energy Technology Assessments* report issued by KIUC in 2005. In future years, KIUC will likely begin paying a capacity charge as well.
- Schedule
  - Two years to obtain permits, site facility, select a vendor, and obtain financing.
  - Three years to construct and acceptance test the facility.

Table 10-2.B presents the planning level cost analysis for the first-year operation of the 110-tpd AD facility in 2011. For comparison to other technology options, the first-year cost analysis offers sufficient detail. The selected technology option may warrant a more in-depth life cycle analysis. The anticipated tipping fees range from approximately $72 to $82 per ton of solid waste processed. R. W. Beck estimates approximately $2,300,300[2] in annual operating and container costs to provide separate collection for 27,055 tons of residential and commercial organics. This yields an additional system cost of per ton of $85 per ton that should be considered when evaluating this system.

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[2] Based on 2005 costs

Table 10-2.B
110-tpd Anaerobic Digestion Facility
2011 First -Year Planning Level Operating Cost Analysis
($ Million)

| Expense | | Low | High |
|---|---|---|---|
| Debt Service | | $1.2 | $1.5 |
| O&M Cost | | $1.1 | $1.2 |
| Preprocessing Residue Disposal | | $0.1 | $0.1 |
| Total Expenses | | $2.4 | $2.8 |
| | | | |
| Revenue | | | |
| Electricity Sale [1] | | $0.4 | $0.5 |
| Compost Sale [2] | | $0.02 | $0.04 |
| Total Revenues | | $0.4 | $0.5 |
| | | | |
| Tipping Fee | ($) | $1.9 | $2.2 |
| | ($/ton) [3] | $72 | $82 |

Note: Totals may not add due to rounding.
[1] Electricity Sale includes an energy charge payment but not a capacity charge payment.
[2] Compost Sale is 75% of the compost may potentially sell as a soil conditioner at $10 per ton on-site. The unsold material is used as alternative daily cover at the landfill.
[3] Tipping Fee was calculated using the 27,055 tons of solid waste received for processing in 2011.

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