Study of Feasible Technologies for Long-Term Management of Municipal Solid Waste on the Island of Kauai

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Acronyms and Abbreviations

AD	Anaerobic Digestion
County	County of Kauai, Hawaii
DOH	Hawaii Department of Health
EIS	Environmental Impact Statement
eWaste	Electronic Waste
FEIS	Final Environmental Impact Statement
FY	Fiscal Year
HDR	HDR Engineering, Inc.
HRS	Hawaii Revised Statutes
ISWMP	Integrated Solid Waste Management Plan
KIUC	Kauai Island Utility Cooperative
LOI	Letter of Interest
MBT	Technical Biological Treatment
MRF	Materials Recovery Facility
MSW	Municipal Solid Waste
MWPF	Mixed Waste Processing Facility
NIMBY	Not-In-My-Back-Yard
PPA	Power Purchase Agreement
RDF	Refuse Derived Fuel
RFP	Request for Proposals
RTS	Refuse Transfer Station
Hawaii	State of Hawaii
SRF	Solid Recovered Fuel
SWD	Solid Waste Division
tpy	Tons per Year
U.S.	United States
WTE	Waste-to-Energy
WTF	Waste-to-Fuel

1.0 Introduction

1.1 Background

The County of Kauai (County), Department of Public Works, Solid Waste Division (SWD), is responsible for administrating solid waste management programs and policies on the island of Kauai, including planning of new and expansion of existing solid waste disposal and handling facilities, and research, planning, and management of source reduction, recycling, special waste management, and public education/awareness programs. The programs and policies are interconnected and reliant on each other to allow proper function of the island's solid waste management system. Key components of the County's existing solid waste management system include refuse collections, refuse transfer stations (RTS), and source reduction and recycling facilities and programs that are integrated with the County-owned and -operated Kekaha Municipal Solid Waste Landfill (Kekaha Landfill).

The Kekaha Landfill is an important component of the County's current solid waste management system and has an estimated remaining capacity of approximately 3 years at current rates of waste disposal. A vertical expansion of the landfill that could extend its capacity approximately 3 years is currently being evaluated. Siting, permitting, and development of a new municipal solid waste (MSW) landfill are expected to take 10 years or more, a timeline substantiated by the County's unsuccessful efforts to permit the New Kauai Landfill and Resource Recovery Park in 2013. The siting effort for that project began in 2000, and a Final Environmental Impact Statement (FEIS) was issued in January 2013. Although an FEIS was issued for the new landfill, development did not occur due to its proximity to the Lihue International Airport and strong opposition from the State of Hawaii (Hawaii) Department of Transportation, Airports Division.

The limited disposal capacity and inability to successfully permit a new landfill within the 10-year timeframe require the County to evaluate and pursue solid waste management alternatives to preserve waste capacity at the Kekaha Landfill. The County is presently evaluating several alternatives for preserving waste disposal capacity, including landfill mining, expansion over the unlined Phase 1 area, increased diversion, and energy-from-waste technologies. The evaluation results will be used by the County to develop a feasible and economical long-term solid waste management solution for Kauai's residents.

1.2 Study Objective

The County initiated this Study of Feasible Technologies for Long-Term Management of MSW on the Island of Kauai (study) due to the limited landfill disposal capacity and development timeline issues described in Section 1.1. The objective of this study involves two steps to identify diversion options to minimize landfilling. First, it evaluates alternative MSW sorting, processing, and energy from waste technologies. Second, it helps determine which of those technologies (or combinations of technologies) could be integrated into the County's solid waste management system at the present time or within the next 5 to 7 years to preserve disposal capacity at the Kekaha Landfill and extend the life of a future landfill.

1.3 Study Preferences and Strategies

The following study preferences and strategies were considered during evaluation of the MSW management technologies:

- Utilize technologies that would:
  1) Result in minimal residual waste that must be disposed of in a landfill (i.e., is an immediate diversion to landfilling);
  2) Directly convert MSW to electric power that would be consumed on Kauai (e.g., energy purchase by the Kauai Island Utility Cooperative [KIUC]); and
  3) Convert MSW to products that have energy value and can be consumed on or exported from Kauai (e.g., waste to fuel).
- MSW generated on Kauai is to be managed on Kauai and not exported off island for processing or disposal. Based on past history within Hawaii, it is acknowledged by the County that off-island disposal would be difficult, if not entirely prohibitive, due to exorbitantly high costs, environmental issues, and public objection.
- The County identifies technologies for consideration and determines whether the technologies are technically feasible or infeasible for commercial deployment on Kauai. The definitions of feasible and infeasible are based on factors determined by the County for successful deployment of the technologies in their solid waste management system.
- Depending on results and recommendations of this study, a Request for Proposals (RFP) meeting Hawaii Revised Statutes (HRS) may be issued for interested technology vendors. The RFP will request priced proposals for projects and/or business opportunities that utilize one or more technologies deemed feasible for commercial deployment.

1.4 Challenges for Managing MSW on Kauai

Management of MSW on Kauai is a long-term issue, and solving it in both environmentally and socially acceptable ways is a major challenge for the County. As described in Sections 1.1 and 1.2, the current remaining disposal capacity of the County's only landfill is limited. The County must commit to finding ways to preserve that capacity and to implement diversion strategies to reduce dependency on landfilling as a primary waste management practice. Landfilling has been a traditional approach to managing MSW on each of the inhabited Hawaiian Islands. As existing landfills age and close, however, siting a new landfill becomes more challenging due not only to technical factors but also to economic, social, and political constraints. Availability of suitable land, Not-In-My-Backyard (NIMBY) syndrome, longstanding federal and state-adopted siting restrictions (e.g., seismic impact zones, fault areas, unstable areas, tsunami zones) and new state legislative siting restrictions (i.e., Act 73) are common challenges for all counties. The shift presents many of the same challenges—as well as new issues—in finding alternative solutions to landfilling.

Collecting and processing recyclables from the MSW stream (e.g., plastics, aluminum cans, paper) has met with challenges in the United States (U.S.). Until 2017, China handled almost half of the world's recyclables to feed its manufacturing boom. In July 2017, China's government announced that it would ban 24 recyclables, including unsorted mixed paper and mixed plastic, starting in January 2018. This ban originates from China's National Sword campaign to crack down on smuggling and contaminated scrap imports. In addition to the ban, China applied strict contamination standards for other recyclables, causing recyclers to seek new markets and evaluate methods to achieve lower contaminant levels (Resource Recycling 2017).

Kauai's recycling program has been subject to unstable market conditions that resulted from China's ban of U.S. recyclables. Other challenges have included the rising costs of shipping, fuel, labor, and other direct program costs. The island's small population and resulting stream of materials recovered do not provide economies of scale for a cost-effective program. Additionally, traditional recyclables (plastics, aluminum cans, paper, cardboard) are shipped out of state for processing, which increases greenhouse gas emissions and the carbon footprint of managing those materials.

Many of the MSW management technologies reviewed in this report include some form of combustion that can contribute to greenhouse gas emissions. Direct combustion of MSW in Hawaii is categorized as a "renewable energy generating resource," and if it produces electric power, it is credited toward the attainment of required Renewable Portfolio Standards for utility companies including KIUC. Alternatively, some technologies produce liquid and/or gaseous "renewable fuels" that could directly displace the fossil fuels that would otherwise be imported to the County. Most all, if not all, of the technologies generate a residual (e.g., ash, char) from the process that requires landfilling or other end-use. The State of Hawaii Department of Environmental Health (DOH) requires a back-up option for MSW disposal during facility shutdowns and residue disposal, which in most cases would be a lined landfill.

The County will continue to face difficult challenges with long-term management of its solid waste for many of the reasons listed here. A solution will need to be balanced and consider technical, economic and political factors that may not be accepted by all County residents. The information provided in this study is intended to help the County make informed decisions in developing a solution.

1.5 Feasibility Study Approach and Report Organization

A summary of the study approach and report organization is shown in Table 1.1. As described in Section 1.2, its objective is to evaluate alternative MSW material sorting and waste-to-energy (WTE) technologies and determine which technologies (or combinations of technologies) could be commercially deployed and successfully integrated into the County's solid waste management system. To meet this objective, this study uses a step-wise approach where each step in the process involves a greater level of detail to successively refine the list of alternative technologies. The list of alternative technologies can then be used to proceed with an RFP phase.

Table 1.1 Feasibility Study Approach and Report Organization

Report Section	Approach
Section 2.0: County-Generated Waste Characteristics	Presents waste and diverted materials quantity and composition estimates using data from existing County studies and plans, including waste characterization studies, 2021 Integrated Solid Waste Management Plan, and annual recycling and diversion reports. Identifies waste and diverted material classes that could be directly diverted or processed for use as a WTE technology feedstock.
Section 3.0: Overview of Technologies	Presents a summary overview and standalone technical memorandum that describes traditional waste processing and WTE technologies, emerging and alternative technologies (conversion technologies), management practices, and current industry trends.
Section 4.0: Letter of Interest and Response Summary	Presents the approach in soliciting responses from technology vendors to provide a technological solution for the County for long-term MSW management on Kauai. Vendor responses are summarized.
Section 5.0: Technology Screening Approach	Presents the classification and performance criteria screening approach used to determine if a technology can be commercially deployed and integrated into the County's solid waste management system.
Section 6.0: Assessment of Combining Feasible Technologies	Presents example approaches in combining feasible technologies in managing the County's waste and diverted

Table 1.1 Feasibility Study Approach and Report Organization

Report Section	Approach
	materials quantity and composition estimates described in Section 2.0.
Section 7.0: Study Summary, Conclusion, and Recommendations	Presents a summary, conclusion, and recommendations in pursuing standalone or combined technologies.

2.0 County-Generated Waste Characteristics

Waste and diverted materials quantity and composition estimates (waste characteristics) are key planning elements in development of long-term MSW management projects. The planning elements are important in sizing waste management facilities to ensure that sufficient capacity is allowed for disposal, material handling, processing, energy generation, and residue management. The elements can significantly affect design and operation of the following processes, adding to the importance of developing accurate estimates during the planning phase:

- Suitability of a particular choice of processing
- Potential for impacts and needs for mitigation resulting from processing and/or landfill disposal
- Energy content and recovery potential of the waste
- Quantity and nature of residues resulting from processing

The methodology and results in estimating waste and diverted materials quantity and composition completed for this study are described in the following sections.

2.1 Waste Generation Estimates

Quantities of landfilled MSW and recyclable materials diverted from the landfill were provided by the County for fiscal year (FY) 2019, FY2020, and FY2021, and waste generation and diversion estimates were developed for the period FY2022 through FY2045 as shown on Table A.1 provided in Appendix A. The estimates are based on data taken from the County's 2021 Integrated Solid Waste Management Plan (ISWMP) and assume an average annual growth rate of 1.29 percent for disposed MSW and that 43 percent of the disposed MSW is diverted recycled material (average diversion rate for FY2019 through FY2021). The waste generation estimates in the ISWMP were prepared based on de facto population estimates, past generation and diversion trends, and potential changes to those trends. Estimates were projected through FY2045 to encompass a 20-year project period and assume a project start date in approximately FY2025.

2.2 Waste Composition Estimates

The composition of a waste stream can be estimated using various methods, one of which is use of statistical data generated from a waste composition study. Waste composition studies are typically performed by municipalities to provide statistically valid data on the types and quantities of waste managed in a solid waste system and to provide waste characterization data in support of long-term solid waste management planning. The County completed the 2017 *Waste Characterization Study* for use in updating their ISWMP (Cascadia, 2017).

Composition percentages for 11 waste categories taken from the above study were applied to the generation estimates for landfilled waste described in Section 2.1 and shown in Table A.1 of Appendix A. Composition percentages were also calculated for five diverted material categories (recyclables) as shown in Table A.1. Percentages were calculated by dividing the flow-controlled quantity (materials managed by or under contract to the County) for each diverted material category by the total diverted materials quantity. The composition percentages were then applied to future year diversion estimates shown in Table A.1.

The estimated quantities and composition of disposed waste shown in Table A.1 represent landfilled materials that could be sorted and diverted for recycling, or sorted, processed, and used as a feedstock source in an energy-from-waste technology. Table A.1 also shows the quantities of current County flow-controlled recycled materials, which could also be used as a feedstock source in an energy-from-waste technology.

3.0 Overview of Technologies

This section presents an overview of waste processing technologies (mechanical technologies) and traditional WTE, emerging, and alternative technologies (conversion technologies) developed and in use in the solid waste management industry. A standalone technical memorandum describing the technologies in more detail, including management practices and current industry trends, is provided in Appendix B. The memorandum is based on HDR's relevant experience and research into these types of technologies, including conducting site tours and inspections of commercial operations throughout North America, Europe, Asia (Japan), the Middle East, and Australia. Due to evolving technological advances in the waste conversion industry, the memorandum most likely does not include all technologies in development now or in the near future. The memorandum provides an in-depth description, project examples, and limitations of the technologies described in the following sections.

3.1 Technology Classes

Waste processing and conversion technologies are typically grouped into the classes described in the following sections.

3.1.1 Thermal Technologies

Thermal technologies are designed to use high temperatures from combustion, gasification, or pyrolysis to convert the combustible materials in MSW feedstocks into a gas, liquid, and other solid by-products (e.g., ash or char). Listed below are examples of thermal technologies:

- Direct combustion (traditional forms of WTE)
- Gasification
- Plasma arc gasification
- Pyrolysis

Traditional thermal processes, such as incineration or WTE technologies, produce electrical power or steam by using a boiler to recover heat formed from direct combustion of MSW. Other thermal processes that convert waste to a liquid fuel and/or synthesis gas (syngas; e.g., gasification, plasma arc gasification, and pyrolysis) can be designed to combust the gas and/or liquid directly in a boiler to produce steam and electricity (similar to a traditional WTE technology) or designed to clean and refine the gas and/or liquid to be combusted in an engine or gas turbine to produce electricity or produce a transportation fuel.

3.1.2 Biological Technologies

Biological technologies are designed to use bacteria in the process to consume the putrescible content of the waste feedstock. This typically occurs in low-temperature environments using either aerobic or anaerobic bacteria (composting or biodegradation, respectively). Listed below are examples of biological technologies:

- Aerobic composting
- Anaerobic digestion with biogas production for electricity or fuel generation
- Mechanical biological treatment

Aerobic composting typically uses source-separated organics as feedstocks including food waste, green waste (e.g., yard, tree trimmings, agricultural wastes), and wastewater biosolids, and is processed in turned windrows or aerated static piles. Anaerobic digestion (AD) is an in-vessel process commonly used to treat wastewater biosolids, industrial/agricultural wastewater, and the organic fraction of the MSW (e.g., food and green waste). AD produces a methane-rich biogas that can be refined into a variety of beneficial fuels including renewable natural gas and compressed natural gas.

Mechanical sorting of the feedstock can be integrated into the process to recover recyclables and remove bulky objects, non-processible items, and other contaminants before biological treatment (i.e., mechanical biological treatment [MBT] technology). MBT technology produces certain recyclables and a solid fuel product that can be further processed to generate energy by another WTE technology designed to process the fuel.

3.1.3 Chemical Technologies

Chemical technologies are more complex in design, using physical chemistry processes to break down or transform various components of a processed waste into building blocks that can be used for chemical feedstock, transportation fuels, or thermal energy. The feedstock for these processes typically requires extensive presorting and preparation to minimize undesirable materials and contamination in the feedstock, and address only a certain type of waste (e.g., plastics, and oils and grease). In many cases, chemical technologies are combined with mechanical, thermal, and/or biological technologies to begin the transformation process to the desired products. Listed below are examples of chemical technologies:

- Hydrolysis
- Catalytic and thermal depolymerization
- Waste-to-fuel

Hydrolysis uses a solvent-based chemical reaction process to break down cellulose fractions in a waste feedstock (e.g., paper, yard waste) to produce sugars, which are fermented to produce an organic alcohol. The alcohol is then distilled to produce fuel-grade ethanol or potentially used as a feedstock for other chemical processes. Depolymerization uses pressure and heat to decompose wastes into a petroleum-like feedstock, which is then processed into fuel types such as synthetic diesel, naphtha, or gasoline. In a waste-to-fuel (WTF) process, a processed feedstock is used to generate a syngas such as hydrogen, methane, or a blend of gases through a thermal conversion process. The syngas is cleaned and synthesized into a liquid or gaseous fuel in the final stages of the technology. Fuel that is produced from the conversion of waste is considered a renewable fuel under Hawaii Statutes.

3.1.4 Mechanical Technologies

Mechanical technologies use equipment and external heat from steam or hot air (not heat produced from combustion or partial oxidation of the waste feedstock) to divide waste into usable products and residue. Most processes produce ancillary products, including recyclables that can be marketed, or the process may start with residual materials from a materials recovery facility (MRF) as the feedstock. The arrangement of the equipment and overall separation processes can vary widely by facility and produce a wide range of output products. Listed below are examples of technologies:

- Autoclave/Steam
- Mixed waste processing (mechanical sorting)
- Refuse-derived fuel (RDF) production
- Solid recovered fuel (SRF) production

Autoclaving is a process that uses heat and pressure in a mechanical, rotating cylinder to separate cellulosic and organic material from other portions of the MSW stream. Recovered cellulose can be used as feedstock for production of low-grade cardboard or as feedstock in composting and AD technologies. Plastics may become feedstock for a depolymerization process or thermal process.

Mixed waste processing is typically classified into two groups: those designed to process source-separated recyclables, commonly referred to as a single-stream or clean MRF; and those that process mixed MSW, a mixed waste processing facility (MWPF) or dirty MRF. These facilities are generally designed to sort and capture traditional recyclables and for pre-screening of other materials or feedstock for other technologies (e.g., MSW residue used to produce fuel for use in a thermal technology). These technologies are front-end sorting systems that are combined with other technologies that require waste fuel from sorted waste streams. For the purposes of this study, they are not considered standalone technologies for final management of waste.

RDF production is a process to produce a fuel product from MSW (e.g., coarse shred, fluff, or pellets) for use in a conversion technology. Separation, shredding, screening, air classifying, and other equipment is used to process MSW into the fuel product.

Solid recovered fuel production is similar to RDF production in that processing steps are added to tightly control moisture, ash, and chlorine content. The added steps produce a fuel product similar in nature to traditional fossil fuels (e.g., coal) that can be used in an industrial boiler for energy production. Industrial boiler applications typically require less stringent emissions standards.

3.2 Combined Technology Use

Several of the conversion technologies listed in the previous sections rely on a combination of two or more technology classes to be operated efficiently and economically as “turnkey” solutions to managing MSW. To illustrate, MBT technologies typically combine mixed waste processing (MRF or MWPF) with biological processing. Waste pre-sorting and processing is required to produce a feedstock suitable for use in the biological process. WTF technologies combine mixed waste processing, and thermal and chemical conversion processes to produce a fuel-based end product. Examples of combined technologies based on the County’s waste and diverted materials quantities and composition are described in Section 6.0.

4.0 Letter of Interest and Response Summary

4.1 Letter of Interest Content

A Letter of Interest (LOI) was prepared to solicit responses from MRF and WTE technology vendors for a description of their technology and company operating information. The intent of the LOI is to assess vendor interest in the study's objective and understand what technologies are currently available and proven for commercial deployment. Responses also provide useful information if an RFP phase is initiated by the County for any selected technologies. The following MSW management specifications formed the basis of the types of technologies solicited for a response:

- Capable of sorting and recycling MSW into marketable commodities;
- Capable of sorting MSW into feedstock for WTE technologies;
- Capable of directly converting MSW to electric power for consumption on Kauai;
- Capable of converting MSW to products having energy value for consumption on Kauai or exported; or
- Capable of combinations of the above technologies.

The LOI disclosed that responses are voluntary and responding to the LOI does not commit the County to pursue or finalize an agreement with any vendor. It was not the intent to finalize a list of vendors or technologies. The responses were used in this study to help assess which types of technologies are commercially viable and could be integrated into the County's solid waste management system, whether as standalone technologies or combinations of technologies. The LOI contained a cover letter, instructions to interested parties, questionnaire, and the waste and diverted materials quantity information described in Section 2.0. A copy of the LOI is provided in Appendix C.

4.2 Summary of Responses

Approximately 70 U.S. and global technology vendors were contacted for interest in responding to the LOI. Fifty of the vendors indicated interest and were sent the LOI. Twenty-five of the 50 vendors submitted a response. Provided below is a breakdown of the types and number of responses received:

- Thermal Technologies: 8 LOI solicitations and 4 responses
- Biological and Chemical Technologies: 34 LOI solicitations and 17 responses
- Mechanical Technologies: 8 LOI solicitations and 4

Table C (Appendix C) summarizes the received vendor responses. All technologies except one provided a diversion approach to solid waste management and can be categorized into one or more of the technology classes described in Section 3.0. The one exception proposed a technology designed to increase landfill disposal volumes instead of direct waste diversion. This is accomplished by injecting steam into the landfill to accelerate waste volume reduction through enhanced biological degradation. The types of responses varied significantly, including responses that presented a standalone technology focused on a smaller segment of the County's waste stream (e.g., organics, non-recyclable plastics) and others that used their technology in combination with other technologies to manage a larger quantity or all of the County's generated waste (e.g., mechanical sorting, RDF processing, and mass burn).

Technologies not explicitly identified and reviewed in the context of this study are not necessarily excluded in future requests by the County. However, the evaluations provided in this report are intended to help guide prospective project developers regarding the feasibility and applicability of respective technologies in Kauai.

5.0 Technology Screening Approach

A two-tiered screening approach was used to classify and comparatively evaluate technologies using performance criteria developed for this study. The objective of the two-tiered screening was to determine if a technology can be commercially deployed and integrated into the County's solid waste management system and to develop a list of technology options (or a combination of options) to be included by the County in an RFP phase.

The two-tiered screening approach is described in the following sections.

5.1 Tier 1 Screening: Established, Emerging, and Undeveloped Classifications

The Tier 1 screening approach segregates technologies into "established," "emerging," or "undeveloped" classifications, which are defined as follows:

- **Established technology class.** A technology is considered established if it satisfies three criteria:
    - It can be demonstrated to meet minimum County-derived commercial readiness performance criteria, including a proven U.S. operating history (minimum of one U.S. operating project);
    - It can be scaled to meet the County's MSW management diversion objective (i.e., it minimizes landfilling); and
    - It is a standalone technology or can be combined with other technologies.

Proven U.S. operating history is evaluated by technology type and not by specific vendor operating history; however, evaluation of the operating history of a vendor would be extremely important for any technology during an RFP phase.

- **Emerging technology class.** A technology is considered emerging if:
    - It is demonstrated at a pilot scale; and
    - A U.S. scaled project will be developed and fully operating within approximately 18 months. Scaled projects operating outside of the U.S. are included in this class. An emerging technology must also demonstrate scalability to meet the County's diversion objective.
- **Undeveloped technology class.** A technology is considered undeveloped if:
    - It is conceptual in nature with no commercial operating history in the size range necessary;
    - It has not been demonstrated at a pilot scale (table-top study); or

- It would not meet the MSW management diversion objective.

The primary difference between the classes is the commercial readiness of a deployed technology to process a waste stream with characteristics similar to those of the County's waste stream. The best way to demonstrate commercial readiness of a technology is to assess development and operating data of a facility that is (or was) processing a feedstock volume and type similar to that of the project being considered. Commercial readiness for this study is based on assessment of referenced facilities provided in the LOI responses to meet the County's objective, industry research, and technical expertise. It is not based on unproven performance claims for an established or emerging technology.

5.2 Tier 2 Screening: Performance Criteria

The Tier 2 screening approach compares and evaluates the established and emerging technologies described in Section 5.1 based on the performance criteria presented in this section. This approach produces a detailed comparison of technologies to identify the feasibility of the technology types and classes that are more suitable for the County's waste stream characteristics. The purpose of the comparative evaluation is not to rank the technologies, but to provide explanations of why and to what extent (comparatively) a technology is deemed to be feasible, conditionally feasible, or non-feasible, including a discussion of attributes and limitations. The comparative evaluation performance criteria for feasibility screening are described as follows:

1. "Commercial Readiness" performance criteria: the degree to which the technology has demonstrated management of a MSW stream, including the status of reference or demonstration facilities operating in the U.S.
2. "Applicability to County's Waste Stream Characterization" performance criteria: the degree to which the proposed technology meets County diversion objectives based on the County's waste stream characterization described in Section 2.0 and Appendix A.
3. "Complements Existing Waste Diversion" performance criteria: the degree to which the technology complements (and does not compete with) existing County diversion programs and enhances diversion from landfilling.
4. "Utilizes Process Output" performance criteria: the degree to which the proposed technology output can be used effectively and efficiently on Kauai (e.g., electrical generation may be more advantageous than renewable natural gas).
5. "Standalone or Combined Technologies" performance criteria: the degree to which the proposed technology can be used effectively and efficiently as a standalone process or must be combined with other technologies to increase diversion.

5.3 Screening Summary

The two-tiered screening approach described in Sections 5.1 and 5.2 was performed on the technology types (not vendor-specific) described in the responses to the LOI solicitation. Summary results of screened technologies are listed below, and descriptive reasons are provided in Table D of Appendix D.

- “Direct Combustion” (traditional forms of WTE) is an established and feasible technology option. Several WTE and direct combustion facilities are operational in the U.S. and globally (including on Oahu) using MSW as a feedstock to produce energy as an output.
- “Materials Recovery Facility” is an established and feasible technology option. This technology is a front-end sorting system that is used for recycling programs and is not considered a standalone technology for final management of waste. Numerous single-stream MRFs are operational in the U.S. to separate recyclable materials for reuse. Single-stream recycling requires implementation of community-based, source-separated recycling programs (e.g., commercial and residential curbside collection programs).
- “Mixed Waste Processing Facility” is an established and feasible technology option. This technology is a front-end sorting system that is used for recycling programs and combined with other technologies that require waste fuel from sorted waste streams. It is not considered a standalone technology for final management of waste. A small number of mixed waste processing MRFs are operational in the U.S., most combined with a technology that requires pre-processing. The objectives of mixed waste processing are similar to those of a single-stream MRF in separating recyclables; however, the process is not as efficient and economical because the recyclables are not pre-sorted from the MSW stream. Recovery of recyclables is an added diversion benefit of mixed waste processing in a combined technology scenario.
- “Refuse-Derived Fuel and Solid Recovered Fuel” are established and feasible technology options. These technologies are front-end sorting and processing systems that must be coupled with thermal systems designed to use the fuel produced. SRF properties are typically more stringent than RDF, which allows the fuel to be used in more types of boilers and thermal plants than RDF. A common example is a RDF boiler system similar to the expansion unit at the City and County of Honolulu H-POWER facility. Other possible RDF and SRF users include a cement kiln, gasifier, or pyrolysis unit. Use of RDF or SRF differs from Direct Combustion in that MSW is pre-processed before it can be used as combustible fuel.
- “Anaerobic Digestion” (AD) is an established and conditionally feasible technology option. There are several AD facilities operational in the U.S. and globally using food waste, green waste, and other organics as a feedstock to

produce energy and a soil amendment product as an output. Fewer facilities are operational in the U.S. that use other types of processed mixed waste as a feedstock (e.g., wastewater biosolids, animal carcasses, contaminated paper). Using processed mixed waste as a feedstock typically increases the operational complexity of a facility, risk of odor issues, and public health concerns (e.g., use of wastewater biosolids to produce a soil amendment product).

- "Gasification" is an emerging and feasible technology option. One U.S. facility began commercial-scale operations in late 2022 and a Canadian facility has been operational since 2016. Other smaller facilities are operational in the U.S. and Canada using a two-stage combustion process combined with a waste heat boiler that could be considered a gasification approach. Multiple facilities are operational in Japan; however, Japan's approach to recycling and other unique waste management practices produces an MSW stream substantially different from other countries. A U.S.-based gasification facility would require a front-end waste processing and/or fuel production technology, such as an MRF, RDF, SRF, or MBT type facility.
- "Pyrolysis" is an emerging and conditionally feasible technology option. There is no known commercial-scale facility in the U.S. that has all operating components (energy recovery, fuel processing, and air pollution control) fully integrated as a combined functioning pyrolysis plant. Use of pyrolysis in the County would require it to be combined with a RDF, SRF, or MBT facility to generate the quantity of required feedstock. Many of these technologies have not been developed to a full-scale facility due to the difficulty of finding feasible and reliable sources of feedstock.
- "Mechanical Biological Treatment" is an emerging and conditionally feasible technology option when employed in combination with a technology that can reliably use the output product. There is at least one known facility in the U.S. using MBT technology; however, the current operational status of the facility is unknown. Several facilities are operational in Europe. Fuel produced by an MBT facility requires an end consumer, and therefore the facility is typically combined with another technology or other energy user (e.g., gasification, WTE, cement kiln, boiler).
- "Plasma Arc Gasification" is an undeveloped and non-feasible technology option. Several pilot and commercial-scale facilities of various sizes have been developed; however, none have a proven sustained operating history when scaled to the County's waste generation levels (significant project failures have occurred). Several changes can occur when small systems are scaled-up in capacity, including, but not limited to, changes in feedstock specifications and feed rates, proper sizing of the gasifier, residue, increased complexity of the air pollution control system, and a substantial increase in energy usage to operate the system. Facilities typically must be combined with a mixed waste processing technology (e.g., MRF, RDF, SRF, MBT) to meet feedstock requirements. Study

research did not reveal an operational facility scaled to meet the County’s needs anywhere in the world.

- “Autoclave/Steam Classification” is an undeveloped and non-feasible technology option. There are no known commercial-scale facilities in operation. One pilot study project was submitted as a response to the LOI. The technology proposes injection of steam into the landfill to increase the rate of biodegradation and settlement of the waste mass. New waste could then be disposed in the settled areas. This technology cannot be easily integrated with current landfill disposal operations.

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6.0 Assessment of Combining Feasible Technologies

Efforts to increase landfill diversion can combine several of the established or emerging feasible technologies listed in previous sections. The goal of any combination is to maximize the value and production/quantity of energy and commodities and minimize landfill disposal. Some technologies are compatible when combined, and doing so can increase the total diversion rate over that achieved by a standalone technology. Examples of combined technologies are presented in this section and are based on the County’s waste characteristics described in Section 2.0. The examples are provided to show how technologies can be integrated; however, they do not take into consideration the financial aspects of integration. Simplified examples with landfill disposal are shown; realizing absolute zero-waste diversion to a landfill would be difficult and cost-prohibitive for the County.

6.1 Examples of Combined Technologies

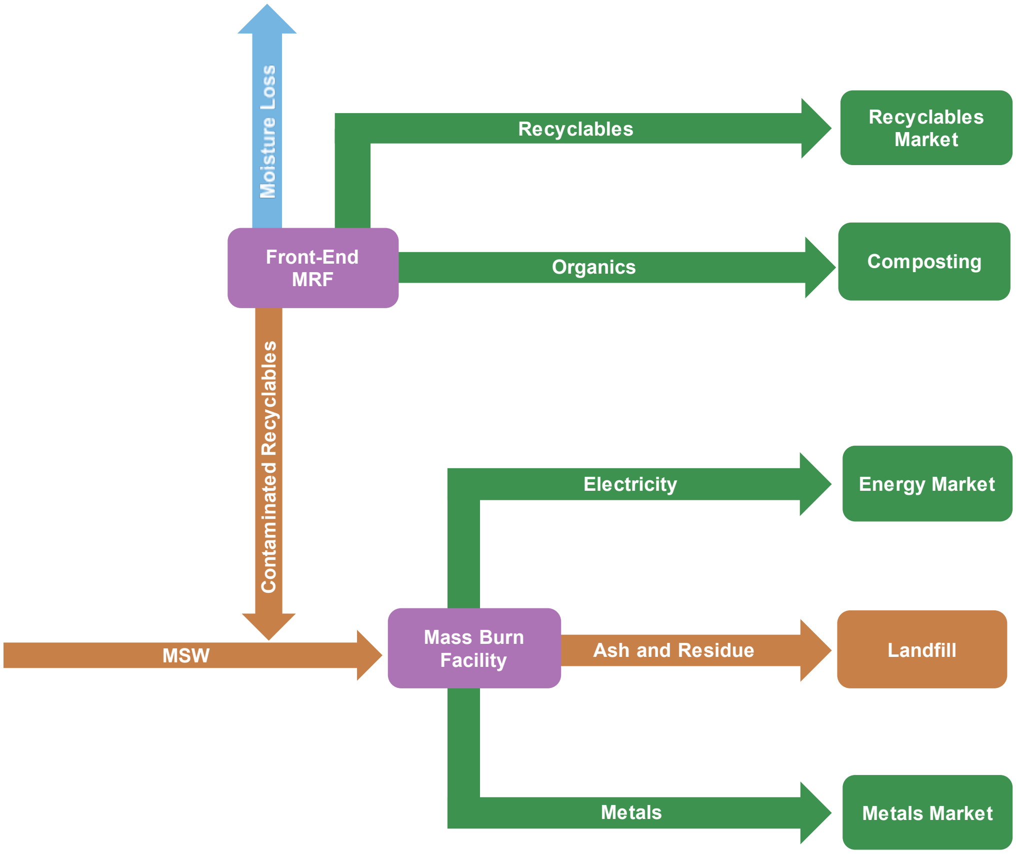
6.1.1 Example 1: Mass Burn with Front-End Processing

Figure 6.1 shows an established mass burn WTE technology combined with the County’s existing recycling and composting programs and front-end MRF. Combining a WTE facility with the existing programs and MRF would reduce the size of the facility needed to manage the County’s waste quantities; however, a WTE facility typically operates more efficiently at a higher feedstock input rate, and the materials that the County currently recycles may need to be considered as a feedstock source to meet the minimum quantities required to efficiently operate a small facility. Energy produced from a WTE facility is currently included as a “renewable energy source” and would help meet State and County renewable goals.

Front-end processing that incorporates a single-stream MRF in support of a curbside collections program would increase the diversion rate of traditional recyclables. Other sorting processes could be located at the MRF to target wood, metal, and concrete from construction and demolition debris wastes; and organic waste. Front-end processing would also help in screening of prohibited wastes (e.g., eWaste, treated lumber). Ash and residue byproducts from a WTE facility would require landfilling.

The volume of material diverted from landfilling for this combined system is approximately 70 percent of the MSW waste stream. The density of WTE ash and residue is higher than that of MSW, which would further increase landfill diversion because higher-density waste requires less landfill disposal volume. The combined technologies are commonly employed at a commercial-scale.

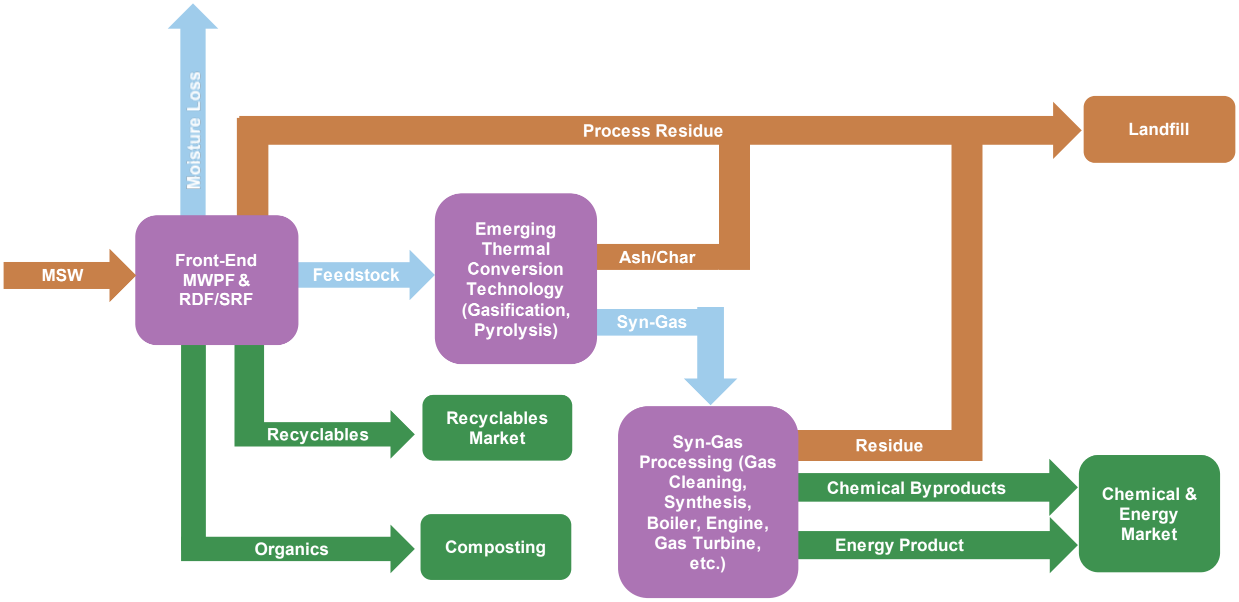
Figure 6.1 Example 1: Mass Burn with Front-End Processing



6.1.2 Example 2: Thermal Conversion with Front-End Processing

Figure 6.1 shows an emerging thermal conversion technology combined with the County's existing recycling and composting programs. Combining a thermal technology with the existing programs requires pre-processing (MRF, MWPF, RDF or SRF) and utilizes a specific fraction of the MSW. Use of specific waste types and specialized pre-processing (e.g., sorting, shredding, sizing) of feedstocks are typical requirements for many thermal conversion technologies. Different thermal technologies can utilize non-recycled and recycled commodities as feedstocks (e.g., recycled and non-recycled plastics), providing an on-island use for the commodities. Combustion of the waste feedstock in a thermal technology produces a syngas, which is converted into fuel for a boiler, engine, or gas turbine for energy production or used in a chemical process, thereby displacing fossil fuels that would otherwise be combusted. The uses typically require further treatment/cleaning to meet end-use standards, which produces a residue waste that requires landfilling. The diversion potential for a combined thermal technology can be similar to or different than that achieved for a WTE technology, depending greatly on the type of technology.

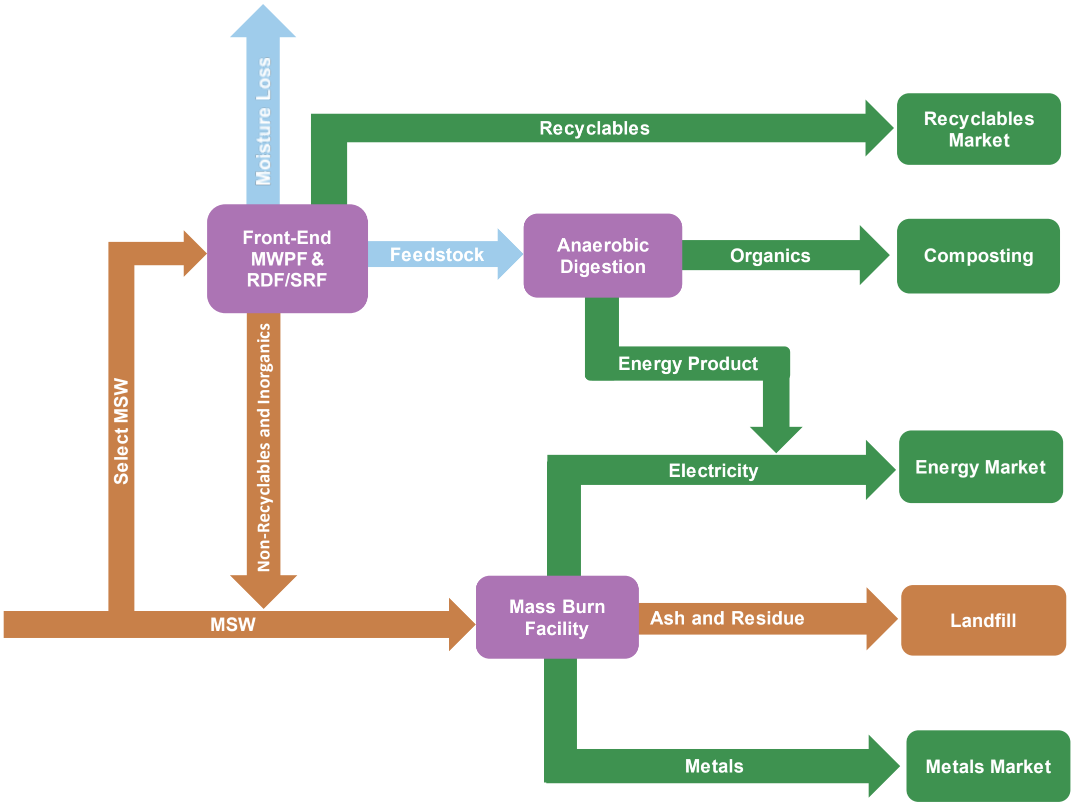
Figure 6.2 Example 2: Thermal Conversion with Pre-Processing



6.1.3 Example 3: Mass Burn with Anaerobic Digestion

Shown in Figure 6.1 is a mass burn WTE facility combined with the County's existing recycling and composting programs, and recovery of organics for feedstock in an AD technology. Enhanced recovery of organics can be accomplished in many ways, including implementing a food and green waste residential curbside collection program, mandatory commercial organics recycling, and wood debris recycling at construction sites. This combination would increase the diversion rate for both traditional recyclables and organics and would produce energy and soil amendment components in the AD system. The remaining waste from the front-end pre-processing is combined with non-select MSW and routed to the mass burn facility for energy production.

Figure 6.3 Example 3: Mass Burn with Anaerobic Digestion



7.0 Study Summary, Conclusion, and Recommendations

7.1 Study Summary

County SWD is responsible for administrating solid waste management programs and policies on Kauai. One of the key components of the County's existing solid waste management system is the Kekaha Landfill, which has an estimated remaining waste fill capacity of approximately 6 years with the planned vertical expansion. The County is evaluating several alternatives for preserving waste disposal capacity, including landfill mining and expansion, diversion, and WTE options. The County will use the feasibility study's evaluation results to develop a feasible and economical long-term solid waste management solution for Kauai's residents.

The County initiated this study because of the extensive effort and timeline necessary to develop a new landfill and the critical need to address the limited disposal capacity at the Kekaha Landfill. The objective of the study involves two steps. First, it evaluates alternative MSW sorting and processing technologies. Second, it helps determine which of those technologies (or combinations of technologies) could be integrated into the County's solid waste management system at the present time or within the next 6 years to preserve disposal capacity at the Kekaha Landfill and extend the need for a new landfill by several years.

To begin the feasibility study, County-generated waste characteristics were assessed, including quantity and composition. These characteristics are key planning elements in development of long-term MSW management projects.

Once waste characteristics were estimated, the following waste processing and conversion technology classes were evaluated:

- **Thermal**, which use high temperatures to convert the combustible materials in MSW feedstocks into a gas, liquid, and other solid by-products;
- **Biological**, which use bacteria in the process to consume the putrescible content of the waste feedstock;
- **Chemical**, which use physical chemistry processes to break down or transform various components of a processed waste into building blocks that can be used for chemical feedstock, transportation fuels, or thermal energy; and
- **Mechanical**, which use front-end processing equipment to sort, shred, and size waste into recyclable materials and fuels for use in thermal conversion technologies.

Several of the conversion technologies rely on a combination of two or more technology classes to be operated efficiently and economically as "turnkey" solutions to managing MSW. Two examples of combined technologies are listed below:

- Mass burn facility with front-end processing
- Thermal conversion with front-end processing

An LOI was then prepared to solicit responses from waste pre-processing (MRF and MWPF) and WTE technology vendors for a description of their technology and company operating information. Approximately 70 U.S. and global technology vendors were contacted and 25 responses were received. This study assessed the responses to identify commercially viable technologies for integration into the County's solid waste management system.

A two-tiered screening approach using performance criteria was developed to classify and comparatively evaluate waste processing and conversion technologies described in the responses to the LOI solicitation. The objective of the two-tiered screening was to determine if a technology can be commercially deployed and integrated into the County's solid waste management system and to develop a list of technology options (or a combination of options) for the County to use in an RFP phase. The following summarizes these two tiers:

- **Tier 1** segregates technologies into "established," "emerging," or "undeveloped" classifications. The primary difference between the classes is the commercial readiness of a deployed technology to process a waste stream with characteristics similar to those of the County's waste stream.
- **Tier 2** compares and evaluates the feasibility of established and emerging technologies based on study-defined performance criteria. The comparative evaluation performance criteria for feasibility is listed below:
    1. Commercial readiness
    2. Applicability to County's waste stream characterization
    3. Complements existing waste diversion
    4. Utilizes process output
    5. Standalone or combined technologies

Below is a summary of the results of the two-tiered screening approach. A detailed summary of feasible technologies and performance criteria is shown in Table 7.1.

- **Established and feasible technologies:**
    - Direct combustion
    - Materials recovery facility[1]
    - Mixed-waste processing[1]
    - Refuse derived fuel and solid recovered fuel
- **Established and conditionally feasible technologies:**
    Anaerobic digestion

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[1] These systems are established and feasible front-end sorting systems for technologies that manage or convert waste.

- **Emerging and conditionally feasible technologies:**
  - Gasification
  - Pyrolysis
  - Mechanical biological treatment
- **Non-feasible technologies:**
  - Plasma arc gasification
  - Autoclave/Steam Classification

Process flow diagram examples were prepared for combined established, and feasible or conditionally feasible technologies to show the combined technologies effect on the County's waste stream. Process flow diagrams were prepared for the following three examples:

- Mass burn with front-end processing
- Thermal conversion with front-end processing
- Mass burn with anaerobic digestion

7.2 Conclusion and Recommendations

The County will continue to face difficult challenges with long-term management of its MSW for the reasons listed in this study. The information provided is intended to help the County make informed decisions in developing a management solution that will consider technical and economic factors. Developing a solution requires, among other considerations, an understanding of the County's specific needs and locally available options, risk profile, appetite for innovation, and financial resource requirements.

The County has sustained a diversion rate of over 40 percent for almost a decade, which is high for a small, geographically isolated municipality. The County's programs include a variety of recycling opportunities, legislation that drives diversion, and ongoing educational programs and outreach. To further increase the diversion rate, significant investments will need to be made in infrastructure and County staffing, and additional ordinances at the local or state level will be required to mandate recycling programs, ban certain materials from landfills, create economic incentives to divert waste, and enforce producer responsibility.

Unless a significant expansion can be permitted at the existing landfill or a new landfill can be sited, permitted, and developed, continued long-term disposal of all non-recycled MSW at the Kekaha Landfill is not a viable alternative due to its limited disposal capacity. Alternative options to landfilling the County's non-recycled MSW include increasing diversion through integration of one or more technologies described in this study or adopting a combination of all or parts of current programs and alternative options.

Table 7.1 Summary of Feasible and Conditionally Feasible Technologies

	Established & Feasible				Established & Conditionally Feasible	Emerging & Conditionally Feasible		
		Front-End Mechanical Processing						
Performance Criteria for Feasibility Screening	**Direct Combustion**	**Materials Recovery Facility**	**Mixed-Waste Processing Facility**	**Refuse Derived Fuel and Solid Recovered Fuel**	**Anaerobic Digestion**	**Gasification**	**Pyrolysis**	**Mechanical Biological Treatment**
1. Commercial Readiness	Yes	Yes	Yes	Yes	Yes	Yes[1]	Yes[2]	Yes
2. Applicability to County's Waste Stream Characterization	Yes	Yes	Yes	Yes	No[3]	Yes	Yes	Yes
3. Complements Existing Waste Diversion (Degree)	High	Low - Med.	Low - Med.	Med.- High	Medium	Highest[4]	Low - High	Med.- High
4. Utilizes Process Output	Yes	No[5]	No[5]	No[5]	Yes	Yes	Yes	Yes
5. Standalone or Combined Technologies	Standalone	Combined, Requires a Thermal Process	Combined, Requires a Thermal Process	Combined, Requires a Thermal Process	Standalone or Combined	Combined, Requires Fuel Refinement	Combined, Requires Fuel Refinement	Combined, Requires a Thermal Process

1. There is at least one known technology in commercial-scale operation in the U.S. and others operational outside the U.S. There are dual-chamber “gasification” technologies operating in the U.S.
2. There are no known facilities operational in the U.S. that processes MSW. U.S. facilities are reported to be under development. One known facility is operational in Texas and uses non-recyclable plastics as feedstock.
3. Would require separate curbside collection of green and food waste. Wastewater treatment plant sludges can also be processed using this technology.
4. Produces vitrified ash (slag) for other uses (less residue requiring landfill disposal).
5. Front-end sorting and processing for other technologies. Not considered final management of solid waste for this study.

Increasing diversion by adopting one or more of the technologies evaluated in this study will require a significant long-term investment by the County. Annual costs are estimated between the low and high range values shown in Table 7.2. Costs are highly dependent on contractual terms, development costs (capital debt service), annual operations and maintenance, and the chosen technology or combination of technologies.

Table 7.2 Estimated Annual Costs[1]

Technology Type[3]	Cost per Ton (Low Range)	Cost per Ton (High Range)	Total Annual Cost (Low Range)[2]	Total Annual Cost (High Range)[2]
Direct Combustion	$160	$240	$15.2M	$22.8M
Anaerobic Digestion	$180	$260	$17.1M	$24.7M
Gasification	$200	$400	$19.0M	$37.9M
Pyrolysis	$240	$360	$22.8M	$34.1M
Mechanical Biological Treatment	$90	$200	$8.5M	$19.0M

1. Cost estimates are for general comparison of technology costs and should not be used for budgetary or other financial purposes.
2. Based on the FY2025 estimated generated waste quantity of 94,830 tons/year shown on Table A.1 (Appendix A).
3. Costs assume integration with a required sorting or processing technology (MRF, MWPF, RDF or SRF), if needed.

Based on the evaluation of available waste management technologies presented in this feasibility study, it is recommended that the County consider implementing one or more of the technologies as a management solution. This would require the County to conduct a formal, cost-competitive, two-stage RFP process for project developers to offer integrated solutions based, in part or in whole, on the established and emerging technologies identified in this study. A two-stage RFP process will provide the County with clear options, reliable cost estimates, and contractual arrangements to develop diversion and alternative waste conversion technologies that would lessen the reliance on the Kekaha Landfill.

The two-stage RFP would require prospective bidders to submit information and comply with specific requirements at each stage of the RFP process in order for the County to make a fully informed and transparent decision on the best waste management solution. Based on information received in Stage 1, the County may decide to proceed with Stage 2.

Examples of the information that vendors would be required to provide or demonstrate in the two-stage RFP process (in addition to County-provided terms and conditions of the project and RFP process) include:

- Stage 1 RFP:

  - Non-collusion affidavit, disclaimer statements, and other RFP requirements of HRS
  - List of participating team entities and key members
  - Minimum financial capacity data and project finance experience
  - Waste diversion technology description, process schematics, mass balance, and energy balance information
  - Reference projects with development and operating data, including capital development, and operating and maintenance costs

- Stage 2 RFP (based on County decision to proceed):
  - Confirmed or updated information provided in Stage 1
  - Project Guarantor Commitments
  - Bank letter of intent to issue letter of credit
  - Insurance company letter of intent
  - Throughput and electricity generation performance guarantees
  - Specifications of major equipment/systems
  - Process residue and liquid discharge data
  - Air pollutant emissions
  - Major equipment replacement schedule
  - Key personnel time commitments
  - Fixed design-build price breakdown
  - Operation and maintenance price breakdown
  - Cost of capital by source
  - Service fee breakdown
  - Escalation indices
  - Guaranteed maximum electricity utilization/demand
  - Proposed location of project and proof of controlling land guarantees/commitments, proper districting, and identified permits
  - Requirements and schedule to secure a Power Purchase Agreement with KIUC or other energy or renewable fuel end-users, if any
  - Waste and quantity data of waste or product streams that would be shipped out of the County

Issuing a two-stage RFP will require significant input by the County to complete the overall process in a timely manner. Legal input will be critical if a Stage 2 RFP is issued to ensure the documents and the process meet all County and State procurement requirements. Stage 1 is estimated to take approximately 180-days to prepare the RFP documents, issue the RFP, respond to questions (addendums), and evaluate the received proposals. Stage 2 is estimated to take approximately 180-days for the same Stage 1 process, with additional time allowed for preparation of responses and to negotiate contract terms.

References

Cascadia Consulting Group (Cascadia), 2017. County of Kaua'i, Waste Characterization Study, 2017 FINAL Report. May.
Resource Recycling, 2017. China Says It Will Ban Certain Recovered Material Imports. 24 July.

Appendices

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Appendix A

Waste and Diverted Materials Quantity and Composition Estimates

County of Kauai Study of Feasible Technologies
Table A.1 - Waste Generation and Composition

Date: April 28, 2023

	Annual Waste Generation, Diversion & Disposal (tons)			Estimated Composition of Disposed (tons)[6]											County Flow Controlled Recyclables for Feedstock[8] (tons)				
Fiscal Year[1]	Total MSW Generated	Total Diverted Material	Total Tons Disposed[5]	Paper (18.4%)[7]	Plastic (11.5%)[7]	Glass (2.8%)[7]	Metal (3.9%)[7]	Food (10.3%)[7]	Other Organics (18%)	Inerts and Other C&D (23.7%)[7]	Electronics and Appliances (1.7%)[7]	Household Hazardous Waste (0.07%)[7]	Special Waste (1.7%)[7]	Mixed Residual (7.3%)[7]	Paper (7.2%)[9]	Plastic (0.13%)[10]	Glass (0.74%)[11]	Green and Wood Waste (36.0%)[12]	Tires (0.25%)
2019[2]	158,659	67,593	91,066	16,756	10,473	2,550	3,552	9,380	16,392	21,583	1,548	637	1,548	6,648	4,867	88	500	24,333	169
2020[3]	156,041	68,325	87,716	16,140	10,087	2,456	3,421	9,035	15,789	20,789	1,491	614	1,491	6,403	4,919	89	506	24,597	171
2021[4]	158,054	67,963	90,091	16,577	10,360	2,523	3,514	9,279	16,216	21,352	1,532	631	1,532	6,577	4,893	88	503	24,467	170
2022	160,093	68,840	91,253	16,791	10,494	2,555	3,559	9,399	16,426	21,627	1,551	639	1,551	6,661	4,956	89	509	24,782	172
2023	162,158	69,728	92,430	17,007	10,629	2,588	3,605	9,520	16,637	21,906	1,571	647	1,571	6,747	5,020	91	516	25,102	174
2024	164,250	70,627	93,622	17,227	10,767	2,621	3,651	9,643	16,852	22,189	1,592	655	1,592	6,834	5,085	92	523	25,426	177
2025	166,369	71,539	94,830	17,449	10,905	2,655	3,698	9,768	17,069	22,475	1,612	664	1,612	6,923	5,151	93	529	25,754	179
2026	168,515	72,461	96,053	17,674	11,046	2,689	3,746	9,894	17,290	22,765	1,633	672	1,633	7,012	5,217	94	536	26,086	181
2027	170,689	73,396	97,293	17,902	11,189	2,724	3,794	10,021	17,513	23,058	1,654	681	1,654	7,102	5,285	95	543	26,423	183
2028	172,891	74,343	98,548	18,133	11,333	2,759	3,843	10,150	17,739	23,356	1,675	690	1,675	7,194	5,353	97	550	26,763	186
2029	175,121	75,302	99,819	18,367	11,479	2,795	3,893	10,281	17,967	23,657	1,697	699	1,697	7,287	5,422	98	557	27,109	188
2030	177,380	76,273	101,107	18,604	11,627	2,831	3,943	10,414	18,199	23,962	1,719	708	1,719	7,381	5,492	99	564	27,458	191
2031	179,668	77,257	102,411	18,844	11,777	2,868	3,994	10,548	18,434	24,271	1,741	717	1,741	7,476	5,563	100	572	27,813	193
2032	181,986	78,254	103,732	19,087	11,929	2,904	4,046	10,684	18,672	24,584	1,763	726	1,763	7,572	5,634	102	579	28,171	196
2033	184,333	79,263	105,070	19,333	12,083	2,942	4,098	10,822	18,913	24,902	1,786	735	1,786	7,670	5,707	103	587	28,535	198
2034	186,711	80,286	106,425	19,582	12,239	2,980	4,151	10,962	19,157	25,223	1,809	745	1,809	7,769	5,781	104	594	28,903	201
2035	189,120	81,322	107,798	19,835	12,397	3,018	4,204	11,103	19,404	25,548	1,833	755	1,833	7,869	5,855	106	602	29,276	203
2036	191,560	82,371	109,189	20,091	12,557	3,057	4,258	11,246	19,654	25,878	1,856	764	1,856	7,971	5,931	107	610	29,653	206
2037	194,031	83,433	110,597	20,350	12,719	3,097	4,313	11,392	19,908	26,212	1,880	774	1,880	8,074	6,007	108	617	30,036	209
2038	196,534	84,509	112,024	20,612	12,883	3,137	4,369	11,538	20,164	26,550	1,904	784	1,904	8,178	6,085	110	625	30,423	211
2039	199,069	85,600	113,469	20,878	13,049	3,177	4,425	11,687	20,424	26,892	1,929	794	1,929	8,283	6,163	111	633	30,816	214
2040	201,637	86,704	114,933	21,148	13,217	3,218	4,482	11,838	20,688	27,239	1,954	805	1,954	8,390	6,243	113	642	31,213	217
2041	204,238	87,822	116,416	21,420	13,388	3,260	4,540	11,991	20,955	27,591	1,979	815	1,979	8,498	6,323	114	650	31,616	220
2042	206,873	88,955	117,917	21,697	13,561	3,302	4,599	12,145	21,225	27,946	2,005	825	2,005	8,608	6,405	116	658	32,024	222
2043	209,541	90,103	119,439	21,977	13,735	3,344	4,658	12,302	21,499	28,307	2,030	836	2,030	8,719	6,487	117	667	32,437	225
2044	212,244	91,265	120,979	22,260	13,913	3,387	4,718	12,461	21,776	28,672	2,057	847	2,057	8,831	6,571	119	675	32,855	228
2045	214,982	92,442	122,540	22,547	14,092	3,431	4,779	12,622	22,057	29,042	2,083	858	2,083	8,945	6,656	120	684	33,279	231

C&D - Construction and demolition debris

ISWMP - Integrated Solid Waste Management Plan

1. Fiscal Year 2019 (July 1, 2019 - June 30 ,2020).
2. Reported by the County in 2021 Integrated Solid Waste Management Plan Update.
3. Reported by the County of Kauai.
4. Estimated based on data from 2021 ISWMP. 8.47 waste pounds per capita per day, 365 days per year, and estimated de facto population projections. Used 1.29% average annual waste increase and 43% average diversion rate.
5. Disposed at Kekaha Landfill.
6. Categories and percentages from 2017 Kauai County Waste Characterization Report.
7. Refer to Table A.2 for further breakdown of waste types.
8. Flow controlled recyclable tons that the County could possibly divert as feedstock for feasible technology. Percentage of Total Diverted Materials
9. Includes cardboard and mixed paper.
10. Includes Non-HI5 plastics.
11. Includes Non-HI5 glass.
12. Includes green waste and wood pallets.

Table 5. Detailed Composition, Overall Kaua'i Countywide Waste Composition, 2016

Material	Estimated Percent	Estimated Tons	Material	Estimated Percent	Estimated Tons
Paper	**18.4%**	**15,441**	**Other Organics**	**18.0%**	**15,107**
Uncoated Corrugated Cardboard	4.4%	3,674	Leaves and Grass	4.3%	3,579
Kraft Paper Bags	1.4%	1,149	Prunings and Trimmings	1.9%	1,585
Newspaper	0.8%	629	Branches and Stumps	0.1%	64
White Ledger Paper	1.3%	1,096	Manures	0.0%	0
Mixed Paper	4.1%	3,472	Textiles	3.0%	2,525
Aseptic and Gable Top Containers	0.4%	323	Carpet	0.6%	508
Compostable Paper	4.4%	3,711	Sewage Sludge	4.8%	3,985
Non-Recyclable Paper	1.7%	1,386	Non-Recyclable Organic	3.4%	2,861
Plastic	**11.5%**	**9,595**	**Inerts and Other C&D**	**23.7%**	**19,815**
PETE Containers - HI-5	0.4%	375	Concrete	1.3%	1,072
PETE Containers - Non-HI-5	0.3%	246	Asphalt Paving	0.0%	3
HDPE Containers - HI-5	0.1%	122	Asphalt Roofing	1.9%	1,566
HDPE Containers - Non-HI-5	0.5%	430	Clean Lumber	5.0%	4,167
Plastic Containers #3-#7	1.1%	958	Treated Lumber	2.9%	2,467
Plastic Grocery and Other Merchandise Bags	0.0%	41	Other Wood Waste	6.2%	5,157
Agricultural Film Plastic	0.1%	80	Gypsum Board	3.4%	2,821
Other Clean Film	0.5%	385	Rock, Soil and Fines	1.7%	1,395
Non-Recyclable Film Plastic	4.1%	3,407	Non-Recyclable Inerts and Other	1.4%	1,166
Durable Plastic Items	1.9%	1,605			
Expanded Polystyrene Food Serviceware	0.4%	364	**Electronics and Appliances**	**1.7%**	**1,446**
Other Expanded Polystyrene	0.3%	236	Covered Electronic Devices	0.2%	138
Non-Recyclable Plastic	1.6%	1,345	Non-Covered Electronic Devices	0.5%	387
			Major Appliances	0.0%	0
Glass	**2.8%**	**2,332**	Small Appliances	1.1%	921
Glass Bottles and Containers - HI-5	0.9%	761			
Glass Bottles and Containers - Non-HI-5	1.3%	1,083	**Household Hazardous Waste (HHW)**	**0.7%**	**626**
Non-Recyclable Glass	0.6%	488	Paint	0.0%	38
			Empty Aerosol Containers	0.1%	70
Metal	**3.9%**	**3,240**	Vehicle and Equipment Fluids	0.0%	0
Tin/Steel Cans	0.5%	438	Used Oil	0.0%	2
Bi-Metal Cans HI-5	0.1%	69	Batteries	0.1%	109
Other Ferrous	1.3%	1,060	Mercury-Containing Items - Not Lamps	0.0%	0
Aluminum Cans - HI-5	0.3%	228	Lamps - Fluorescent and LED	0.0%	8
Aluminum Cans - Non-HI-5	0.1%	78	Remainder/Composite Household Hazardous	0.5%	399
Other Non-Ferrous	0.6%	530			
Remainder/Composite Metal	1.0%	838	**Special Waste**	**1.7%**	**1,415**
			Ash	0.2%	130
Food	**10.3%**	**8,635**	Treated Medical Waste	0.0%	4
Retail Packaged Food - Meat	0.5%	432	Bulky Items	0.4%	335
Retail Packaged Food - Non-Meat	2.8%	2,361	Tires	0.0%	9
Unpackaged Food - Meat	0.9%	787	Remainder/Composite Special Waste	1.1%	937
Other Packaged Food - Meat	0.6%	522			
Unpackaged Food - Non-Meat	4.3%	3,597	**Mixed Residue**	**7.3%**	**6,089**
Other Packaged Food - Non-Meat	1.1%	936	Mixed Residue	7.3%	6,089
			Totals	**100.0%**	**83,740**
			Samples	**162**	

Confidence intervals calculated at the 90% confidence level. Percentages for material types may not total 100% due to rounding.

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Appendix B

Technical Memorandum: Overview of Technologies

Technical Memorandum

Overview of Technologies

Waste Processing, Waste-to-Energy and Conversion Technologies

Prepared For:
County of Kauai
Study of Feasible Technologies for Long-Term Management of MSW on the Island of Kauai

Prepared By:
HDR Engineering, Inc.

April 28, 2023

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Acronyms and Abbreviations

°F	degrees Fahrenheit
ACI	activated carbon injection
AD	anaerobic digestion
APC	air pollution control
Btu	British thermal unit
C&D	construction and demolition
CAA	Clean Air Act
CFR	Code of Federal Regulations
CH4	methane
CO	carbon monoxide
CO2	carbon dioxide
County	County of Kauai
DWRF	Drake Water Reclamation Facility
ECS	eddy current separators
EPA	U.S. Environmental Protection Agency
FB	filter baghouse
FT	Fischer-Tropsch
H2	hydrogen
HCl	hydrogen chloride
HDPE	high-density polyethylene
HDR	HDR Engineering, Inc.
HRSG	heat recovery steam generator
IGCC	integrated gasification combined cycle
IRBF	Indian River Biofuels Facility
IW	industrial waste
MBT	mechanical biological treatment
MRF	materials recovery facility
MSW	municipal solid waste
MWPF	mixed-waste processing facility
N2	nitrogen

Acronyms and Abbreviations (cont.)

NHSM	Non-hazardous Secondary Material
NOx	nitrogen oxides
PAG	Plasma Arc Gasification
PET	polyethylene therephthalate
PVC	polyvinyl chloride
RDF	refuse-derived fuel
SCNR	selective non-catalytic reduction
SCR	selective catalytic reduction
SDR	spray dryer absorbers
SOx	sulfur oxides
SRF	solid recovered fuel
SWD	Department of Public Works, Solid Waste Division
syngas	synthesis gas
tpd	tons per day
U.S.	United States
USD	U.S. dollars
WTE	waste-to-energy
WWTP	Wastewater Treatment Plant

1.0 Introduction

This technical memorandum was prepared by HDR Engineering, Inc. (HDR), for the County of Kauai (County), Department of Public Works, Solid Waste Division (SWD). The memorandum provides an overview of traditional waste-to-energy (WTE) and emerging technologies, management practices, and industry trends. The County is reviewing traditional, emerging, and alternative technologies, often called conversion technologies, that use waste as an acceptable and achievable resource. HDR has prepared this memorandum based on relevant experience and research into these technologies, including site tours and inspections of technologies in use throughout North America and the world (e.g., Europe, Asia [Japan], the Middle East, and Australia). Conversion technologies are a rapidly developing and evolving industry. HDR provides an overview of these technologies and current applications at the time of this report; however, the report does not represent or cover all technologies that may be in development now or in the near future.

The technology development process can provide improved waste utilization instead of simply landfilling what cannot be recycled. The process may be completed in multiple ways, by more than one development team, using varying technologies at various stages of development. Broadly, a technology goes through three developmental stages: laboratory or emerging, pilot or demonstration, and commercial. The process of passing from one developmental stage in the process to the next is often hard to define, as development may be on a continuum or involve various sub-steps along the way.

Emerging technologies are often small-scale operations completed in a laboratory setting and do not have demonstrated facilities that have been operated on a commercial basis with full-scale, complete processes. The technology may work well in a laboratory setting or for a select waste material, but it has not been demonstrated with mixed waste or even select portions of municipal solid waste that can be separated readily from the remaining waste. It is likely that the laboratory model will not have a fuel preparation or energy recovery process, even if these technologies are off-the-shelf systems.

Pilot-scale or demonstration-level technologies have advanced far enough that they may have a test facility where the development team will make test runs of varying and increasingly complex waste mixtures. Initially, a pilot facility may not have all the waste preparation, energy recovery, and pollution control equipment fully integrated, but the process begins to gradually resemble and perform as a complete system. The development may go through several stages and increase in size and complexity as the technology advances. The demonstration facility will look very similar to a commercial facility toward the end of this stage.

Commercial-scale means that at least one fully integrated facility has been built and has been in continuous operation long enough to have gone through several operation cycles and proven that it can reliably achieve the anticipated level of performance. It often takes several years for a technology to be considered commercial. This allows time for planned and unplanned outages to occur, waste materials to pass through short-term and seasonal changes, and a better understanding of the operational and maintenance costs and limitations to develop. Sometimes other innovators will have similar processes along the development curve, but not all related technologies will become commercial at the same time. While development risk is never fully eliminated, risk of technology failure drops substantially once commercial operation is reached.

1.1 General Description

Waste processing and conversion technology options can be grouped into the following technology classes:

- Thermal technologies:
    1) Direct combustion (various forms of traditional waste-to-energy)
    2) Gasification
    3) Plasma arc gasification
    4) Pyrolysis
- Biological technologies:
    1) Aerobic composting
    2) Anaerobic digestion with biogas production for electricity or fuel generation
- Chemical technologies:
    1) Hydrolysis
    2) Catalytic and thermal depolymerization
- Mechanical technologies:
    1) Autoclave/Steam classification
    2) Mixed waste processing
    3) Refuse-derived fuel (RDF) production

It is important to note that some waste conversion technologies are a combination of two or more technology classes. For example, mechanical biological treatment (MBT) technologies combine mechanical separation and treatment with biological processing, while waste-to-fuel technologies combine mechanical pre-processing with thermal and chemical conversion processes, sometimes including a biological component such as anaerobic digestion (AD). Each vendor promoting their technology will have unique features and approaches that may differ slightly from the descriptions provided below. For example, gasification may employ a two-stage gasification process or a single chamber where the waste fuel is gasified, and one technology may require more or less fuel preparation than another gasification technology.

2.0 Conversion Technology Processes and Methodologies

2.1 Thermal Technologies

Thermal technologies are designed to use high temperatures from combustion, gasification, or pyrolysis to convert the carbonaceous combustible materials in municipal solid waste (MSW) feedstocks into a gas and other solid by-products (ash/char). The caloric energy contained in the waste may be recovered to produce an energy product, or the gases produced from the exothermic reaction that breaks down the waste may be further refined into a synthesis gas (syngas) or chemical. Traditional thermal processes, such as incineration or WTE technologies, produce electrical power or steam by using a boiler to recover the latent heat in the exhaust gas formed from combusting the waste. The steam produced is then sent to a turbine generator to generate electricity. Some thermal facilities may also sell the steam or hot water directly to a commercial/industrial user or send it to a district energy system.

Thermal processes that convert waste to liquid fuel and/or syngas (i.e., gasification, plasma arc gasification, and pyrolysis) may be designed to either combust that gas and/or liquid directly in a boiler to make steam and electricity (similar to a traditional WTE technology) or to clean and refine the gas and/or liquid to be combusted in an engine or gas turbine to make electricity. In addition, there are technologies designed to use gasification or pyrolysis to produce a syngas and/or liquid that is cleaned and further refined through a chemical or catalytic process to produce commercial-grade chemicals or liquid synthetic fuel for fixed or mobile internal combustion engines, fixed turbines, or commercial airliners. The gas produced by gasification technologies is composed mostly of hydrogen and carbon monoxide (CO), and there are some technologies that attempt to further refine and capture the hydrogen gas for reuse. Gasification and similar technologies can be highly complex, may be effective on only a limited fraction of the waste stream, and are generally less commercially developed than traditional WTE technologies.

Regardless of the specific thermal process used, direct waste combustion or gasification produces certain types of impurities and constituent air emissions. The quantities vary depending on the type of technology and must be controlled or removed through refining or cleaning. In theory, emissions from gasification and pyrolysis technologies are lower than emissions from traditional WTE technologies that directly combust the waste with an oxygen-rich environment; however, modern emission control systems are required to reduce emissions from both types of technologies below any regulatory emission standards.

Thermal technologies can yield gases such as carbon dioxide (CO2), water vapor, nitrogen oxides (NOx), sulfur oxides (SOx), hydrogen chloride (HCl), particulate and particulate-related emissions (such as heavy metals), and trace amounts of products of incomplete combustion, such as CO and dioxins and furans. New thermal technologies are expected to use modern air pollution control (APC) devices for emissions cleanup. The array of APC equipment available for use in minimizing air emissions is diverse and includes but may not be limited to selective catalytic reduction (SCR) or selective non-catalytic reduction (SNCR) for NOx emissions reduction; spray dryer absorbers (SDA), wet scrubbers, and sorbent injection for acid gas reduction; activated carbon injection (ACI) for mercury and dioxins reduction; and a fabric filter baghouse (FB) for particulate and heavy metals removal. Combustion control techniques are used to control CO and optimize the other APC equipment. Continuous emission monitoring systems, specific operating parameters, and periodic compliance testing are used to demonstrate emission compliance. The complexity of the optimal APC and gas cleanup systems may vary depending on the thermal technology used and the desired end use of the gases and/or liquids produced.

2.1.1 Direct Combustion

Direct combustion technologies with energy recovery, such as mass burn technology and RDF combustion, have been used since the 1950s and continue to be constructed and operated around the world. This technology was first introduced in the United States (U.S.) in the early to mid-1970s, and many of the facilities operating currently have been online for 25 to 40 years. Direct combustion, referred to herein as traditional WTE or Energy from Waste, is the most widely demonstrated and commercially viable thermal conversion technology available, with approximately 4,000 installations worldwide.

The majority of the 70+ thermal waste conversion facilities operating in North America use direct combustion technology. Significant construction of traditional WTE facilities in North America stopped in the mid-1990s, but several existing WTE facilities in Minnesota, Florida, and Hawaii have undergone recent expansions. Two new greenfield facilities have been constructed using modern WTE combustion technology. These include a 3,000-tons-per-day (tpd) mass burn facility in West Palm Beach, Florida (2015), and a 480-tpd mass burn facility in Clarington, Ontario, Canada (Durham York Region), shown in Figure 1. Additional exploratory expansion work is also underway at a number of facilities in the U.S., and the early siting study and funding are being prepared for a greenfield facility in Canada.

Figure 1: Durham York Energy Centre (Ontario, Canada)

Direct combustion of waste involves the complete oxidation of a fuel by combustion under controlled conditions using more than stoichiometric levels of oxygen (also known as excess air combustion). The latent heat generated from the combustion process is recovered in a boiler to generate steam, which can be used directly for heating/industrial purposes or passed through a steam turbine-generator to create electricity. There are several types of direct combustion technologies used on a commercial scale in North America, Europe, and Asia.

The most common direct combustion technologies include:

- Mass burn with a grate system
- RDF stoker-fired boilers
- Modular starved air systems
- RDF fluidized bed combustion

RDF processing is further discussed below. Mass burn combustion technology can be divided into two main types:

- Grate-based, waterwall boiler field erected installations
- Modular, shop-fabricated combustion units with waste heat recovery boilers

The modular units are typically limited to less than 200 tpd and were historically used in facilities where the total throughput is less than 500 tpd. All direct combustion technologies require advanced APC to reduce or remove air emissions before the flue gas is discharged to the atmosphere. The most common examples of APC equipment used at traditional WTE facilities include SCR, or SNCR for NO_x emissions reduction; SDA or dry sorbent scrubbers for acid gas reduction; ACI for mercury and dioxins reduction; and a fabric FB for particulate and heavy metals removal.

The larger mass burn combustion units with waterwall boilers are generally sized from 200 tpd up to as large as 1,000 tpd, with facilities generally sized at 400 tpd to 3,000 tpd or more. MSW is fed directly into a boiler system with little to no pre-processing other than the removal of large bulky items such as furniture and white goods. The MSW is typically pushed onto a grate by a ram connected to hydraulic cylinders where it is combusted. Air is admitted under the grates, into the bed of material, and additional air is supplied above the grates to thoroughly complete combustion of the MSW. The resulting flue gases pass through the boiler, and the heat energy is recovered in the boiler tubes to generate steam. This creates three streams of material: steam, flue gases, and ash.

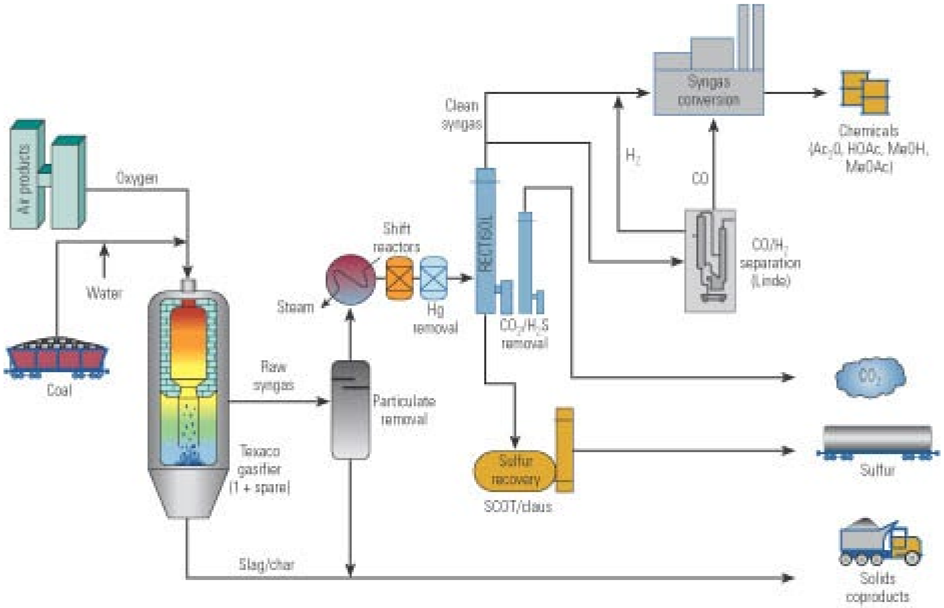
In the smaller modular mass burn systems, MSW is fed into a refractory lined combustor where the waste is combusted on refractory lined hearths or within a refractory lined oscillating combustor. Typically, there is no heat recovery in the refractory combustors. Instead, the flue gases exit the combustors and enter a heat recovery steam generator, or waste heat boiler, where steam is generated by the heat in the flue gas, resulting again in steam, flue gases, and ash.

RDF combustion technologies prepare MSW by shredding, screening, and removing non-combustible materials prior to thermal conversion. The goal of this technology is to derive a better, more homogenous fuel (uniform in size and composition) that can be used in a more conventional solid-fuel boiler as compared to a mass-burn combustion waterwall boiler. RDF is blown or fed into a boiler for semi-suspension firing. Combustion is completed on a traveling grate. Thermal recovery occurs in an integral boiler. The APC equipment arrangement for an RDF facility would be similar to that of a mass-burn combustion system.

2.1.2 Gasification

Gasification has been used for over 200 years. In the 1790s, “coal gas” was used for factory lighting. In the 1940s, during World War II, Germany used wood and coal gasification to synthesize fuels for vehicles and aircraft. Starting in the 1970s and continuing to the present day, the fuel gas produced from the gasification of coal (shown in Figure 2) and various types of biomass (e.g., wood and woody wastes) has been used on a smaller scale to fire stationary internal combustion engines or as a building block to produce liquid fuels.

Figure 2: Typical Gasification Process Utilizing Coal



The gasification process is similar for waste facilities and involves the conversion of carbonaceous material (such as MSW) into a raw gas, often called a producer gas, that contains principally CO, hydrogen (H_2), methane (CH_4), other light hydrocarbons, water, CO_2, and nitrogen (N_2), depending on the specific process. The conversion of the feedstock using gasification typically occurs in a reducing environment (i.e., in the presence of limited or substoichiometric amounts of oxygen) under high temperatures. In some cases, steam is added to the process to alter the ratio of the combustible gases. The relative concentration of producer gas components depends on the composition of the feedstock and process operating conditions.

Gasification is a thermochemical process that performs more consistently when converting homogenous or uniform feedstock. As a result, the feedstock for most gasification technologies must be prepared from the incoming MSW through shredding and pre-sorting to pull out bulky materials, hazardous household waste, recyclables, and inert materials such as dirt, glass/grit, and metals. These materials must be separated and removed to prevent slag formations that can upset the process or cause potential operating issues.

Syngas can be derived from the producer gas by removing impurities and contaminants through appropriate cleaning and reforming processes to produce a gas composed primarily of CO and H_2. The relative concentration of syngas components depends on the composition of the feedstock and process operating conditions (e.g., temperature, air, oxygen, or steam injection, pressure). The typical breakdown of syngas components for gasification technologies that process MSW streams is provided in Table 1. Many gasification technologies are sensitive to the composition of materials processed, and operators will adapt the fuel preparation steps based on experience. The outputs provided in Table 1 are heavily dependent on the waste type used as feedstock.

Table 1: Typical Syngas Composition

Constituents	Output by % Volume	Output in m^3/kg - Waste Processed	Energy Output in Btu/lb - Waste Processed
Hydrogen (H_2)	30%–50%	0.25–0.50	1,360
Carbon Monoxide (CO)	25%–70%	0.25–0.60	1,940
Carbon Dioxide (CO_2)	0%–35%	0.05–0.25	0.00
Methane (CH_4)	0%–10%	0.00–0.15	425

Note: Syngas composition data based on available data from technology vendors including, but not limited to, Thermoselect, Ebara, Taylor, and Sierra Energy. Data is provided as dry percentages. Btu/lb = British thermal units per pound; m^3/kg = cubic meters per kilogram.

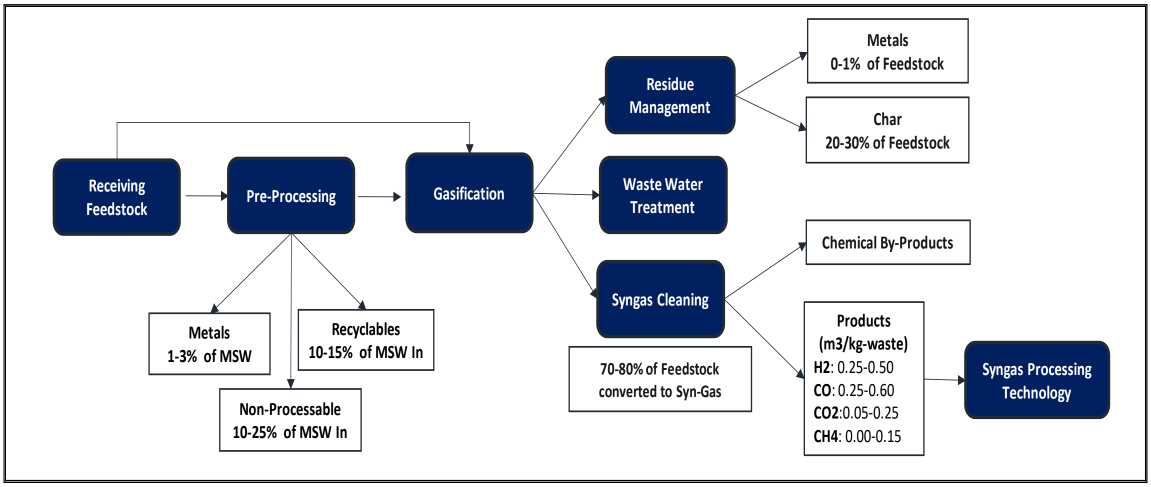
The latent heat in the raw producer gas or syngas could be recovered in a boiler or a heat recovery steam generator (HRSG) to create steam that can be used to generate electricity through a steam-condensing turbine (similar to the traditional WTE technology). Some systems could be designed to use syngas as a fuel to generate electricity directly in a combustion turbine or internal combustion engine (similar to a landfill gas-to-energy system). The generated syngas could also be used as a chemical building block in a catalytic or Fischer-Tropsch (FT) process for synthesis of chemicals and liquid fuels (e.g., methanol, ethanol), but only after cleanup of the gas and synthesized end-product.

There are a wide variety of technology designs that can be defined as gasification, but these types of facilities have generally been smaller than most direct combustion facilities. Figure 3 shows a representative facility in Japan. Some modular combustors operate on the principles of gasification through a two-stage combustion process in which the first (primary) chamber operates in a low-oxygen or starved air-reducing environment, and burnout of the combustion gases produced is completed in a secondary chamber before they pass on to a waste heat boiler. Some systems are designed to vitrify the ash into slag that can be recovered as road base material or other aggregate products, potentially reducing waste volume by more than 95 percent.

Figure 3: Homan Gasification Plant (Fukuoka, Japan)

Figure 4 provides a gasification technology schematic with a range of values for the typical reported outputs.

Figure 4: Schematic of Typical Reported Gasification Technologies



Note: Projected syngas products are equivalent to those indicated in Table 1 above.

Gasification facilities that combust the syngas generated by the process will have air emissions similar to those of traditional WTE facilities. However, the volume and concentration of the air pollutants should theoretically be lower. If the syngas is conditioned for use elsewhere (e.g., as part of a catalytic process to generate a liquid fuel), additional gas cleaning and conditioning equipment is required. These technologies also produce small amounts of char or ash in quantities similar to or less than traditional WTE technologies (less than 90 percent by volume and less than 20 percent by weight). Other metals and inert materials can remain with the char and ash and may be recovered after processing.

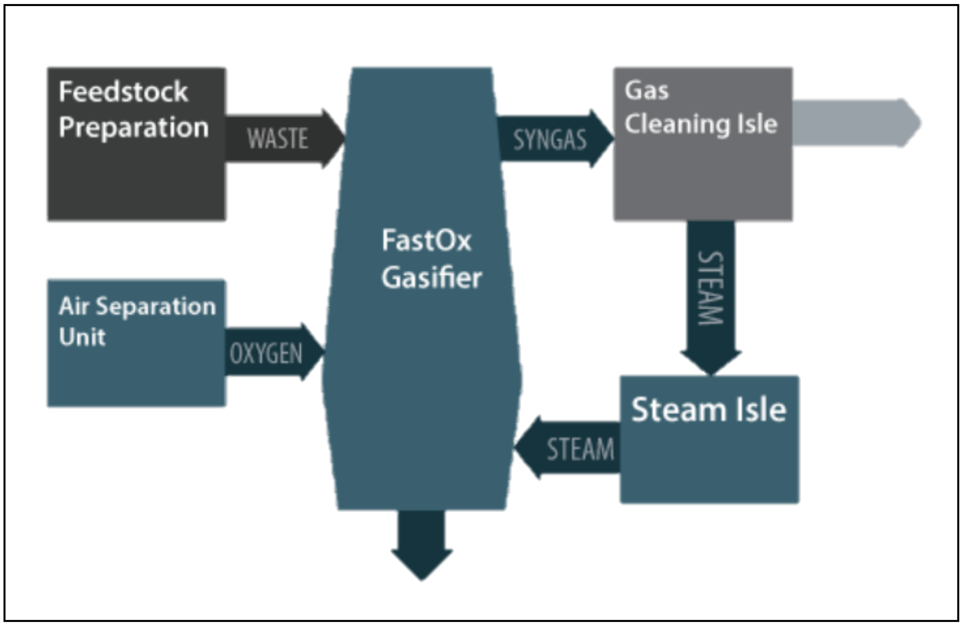
There are several commercial-scale gasification facilities in operation, some of which have been operating for several decades. Most of these facilities are located in Asia, particularly in Japan, and a few are in Europe. The facilities generally process feedstock materials using units sized from approximately 100 to 275 tpd. Some gasification facilities in Japan utilize feedstocks with high energy content, such as select industrial waste (IW) or a combination of these feedstocks and MSW. The drivers for the use of gasification in Japan are largely related to the lack of available landfill capacity and very stringent emission standards, which favor the use of this technology. In addition, waste tipping fees in Japan are much higher than those in the U.S. (more than $250/ton U.S. dollars [USD]), which makes these facilities more financially viable. One goal of the process is to generate a stabilized vitrified ash product that can be reused beneficially as an aggregate in the construction industry to limit the amount of material diverted to scarce landfills. However, the use and marketability of this material in the U.S. is not fully demonstrated.

Thermal MSW and IW gasification has been attempted for many years, particularly in North America, but many of these facilities experienced difficulties scaling up to commercial operations. Currently, gasification technologies in North America are mostly limited to demonstration or pilot scale operations with limited operational history. This is due partially to economics driven by low electricity prices and lower landfill tipping fees in the U.S. It is also due to the costs and difficulties associated with front-end MSW processing to achieve a homogenized and higher Btu-content MSW feedstock suitable for some gasification technologies. In addition, many of the gasification facilities are having difficulty consistently meeting the gas quality and energy content of the syngas to allow the engines or other power operating equipment to efficiently produce electricity.

More recent projects and developments in North America include a Canadian facility developed in 2016 by Enerkem's Alberta Biofuels (Enerkem) that uses proprietary pressurized fluidized bed gasification technology followed by catalytic conversion of syngas to methanol. In 2022, Fulcrum BioEnergy began production of renewable transportation fuels from waste at their Reno, Nevada, facility utilizing gasification and Fisher-Tropsch technologies. Both the Enerkem and Fulcrum BioEnergy facilities are further described in Section 2.3.3.

Ways2H is a Japanese technology that advertises to produce hydrogen from MSW using their proprietary gasification technology. The hydrogen can be used as a transportation fuel. The technology has been tested in Japan on a small scale and on a project in Kern County, California. The Sierra Energy FastOx technology is a fixed-bed gasification system that feeds MSW into the top of the gasifier vessel through an airlock chamber, and purified oxygen and steam are injected into the base of the vessel. As the waste travels down the reaction vessel, it passes through several reaction zones, reaching the hottest area at the base of the vessel where the gasification reaction occurs at temperatures of approximately 2,200 degrees (°) Celsius (4,000°Fahrenheit [F]). The FastOx system includes equipment for feedstock preparation, gasification, syngas conditioning, and final product conversion to fuels or energy. Figure 5 provides a schematic of the FastOx process. Sierra claims that the FastOx gasification system can accept most wastes, with the exception of radioactive and explosive materials. This includes MSW and IW (including hazardous wastes), biomass, construction and demolition (C&D) waste, and medical wastes. The syngas produced via FastOx gasification is designed to be converted into a wide range of sustainable and marketable energy products including electricity, diesel, hydrogen, and ammonia. Sierra Energy is currently operating a small, 20-tpd unit for the U.S. Army and Department of Defense at Fort Hunter Liggett in California. The facility is designed to process MSW and biomass to produce electricity and biodiesel. They are currently developing a commercial-scale version of the FastOx gasifier, called the Pathfinder, which will be designed to process 50-tpd per unit.

Figure 5: Sierra Energy FastOx Process Schematic



Source: Sierra Energy.

2.1.3 Plasma Arc Gasification

Plasma Arc Gasification (PAG) is considered a subset of thermal gasification. Plasma arc melting technology has been used in the metal industry since the late nineteenth century. PAG technology has been used more recently, mostly overseas, as a disposal option for a range of industrial and other disposal applications such as the gasification of hazardous waste, auto shredder fluff, and other types of homogeneous wastes and ash treatment. This technology has been considered a possible source of MSW feed stock disposal and conversion at demonstration and pilot-scale level applications only within the last 15 to 20 years.

Plasma arc technology uses carbon electrodes to produce a very-high-temperature arc ranging between 5,000 and 12,000°F that “vaporizes” the feedstock. The high-energy electric arc that is struck between the two carbon electrodes creates a high-temperature ionized gas (or plasma). MSW and other organic compounds are fed into the reaction chamber, and the intense heat of the plasma breaks them into basic elemental compounds. As the feedstock gasifies, a low-Btu syngas is generated, similar to other gasification technologies, that could be suitable for combustion and heat recovery in a boiler. In theory, the high temperatures produced by a PAG technology produce a cleaner (i.e., lower in tars or other impurities) and higher-quality syngas than other technologies that can be more easily cleaned and combusted directly in an internal combustion engine or gas turbine to produce electricity and/or thermal energy (i.e., steam, hot water). The gas can also be cleaned and used for a chemical process. The inorganic fractions (e.g., glass, metals) of the MSW stream in a PAG system are melted to form a liquid slag material that vitrifies to encapsulate toxic metals when cooled. The systems may be designed to recover recyclable and other materials through a pre-processing system. Metals may be recovered both from feedstock pre-processing and from post-processing the solid slag material.

Similar to other gasification processes, the MSW feedstock requires pre-processing to shred and homogenize the size of the feedstocks, as well as to remove materials that may cause potential operating issues. Vendors of this technology claim that the energy efficiencies capable with PAG systems are higher than those from direct combustion and other gasification technologies. These higher efficiencies are theoretically possible if an integrated gasification combined cycle (IGCC) power system is incorporated to harness the energy in the syngas; however, this has not been proven for PAG systems on a commercial scale.

Vendors of this technology claim to achieve lower emission concentrations than more conventional technologies (i.e., direct combustion). However, air pollution control equipment is still required to clean the gas from the syngas combustion, as these facilities generally have air emissions issues similar to those of other gasification, pyrolysis, and direct combustion facilities. Mercury and other, more volatile metals are expected be driven off with the gas and will need to be removed from the gas combustion device’s exhaust.

Individual units in Japan and around the world are sized anywhere from approximately 20 to 200 tpd and are sometimes combined in multi-unit configurations when developing a facility to process 400 tpd or greater. Although Japan has approximately 10 to 15 years of operating experience, their facilities are used mainly for ash melting (as described below), industrial waste, or MSW with high plastics content that increases the BTU value. Several facilities operate in Japan—most notably, three developed by Hitachi Metals—in Yoshii, Utashinai, and Mihama-Mikata. These facilities are referred to as plasma direct melting reactors. The name is significant due to the desire in Japan to vitrify ash from mass-burn WTE facilities.

Many gasification facilities in Japan also accept ash from conventional WTE facilities for vitrification. In many cases, the primary function of these facilities is ash vitrification rather than energy recovery. The benefit of the vitrified ash is that it binds potentially hazardous elements, thereby rendering the ash inert. Most facilities in Japan use this vitrified ash as an aggregate product. Because of the high MSW tipping fees and other economic drivers in Japan, and the fact that the PAG facilities operate only about 9 months per year, any data from these facilities are difficult to correlate to conditions in the U.S.

There have been some recent attempts at applying PAG technology commercially in North America and in the United Kingdom. However, these attempts have met financial hurdles. In April 2012, after 5 years of planning, construction of a large-scale PAG facility in Saint Lucie County, Florida, was cancelled. An NRG/Adaptive Arc was in the permitting/approvals phase for a facility in Atlantic County, New Jersey, but was eventually canceled. A demonstration project located in Ottawa, Ontario, Canada (i.e., the 110-tpd Plasco Trail Road Facility), also utilized the principles of plasma arc gasification on a mixed MSW waste stream. However, after almost 8 years of sporadic operations and design issues, the facility ultimately closed due to funding issues. The 1,000-tpd Tees Valley 1 and 2 projects in the United Kingdom are shown in Figure 6. However, both projects ran into technical issues and also failed to achieve commercial operation. The project was canceled at a loss of almost $1 billion USD for the project sponsor, Air Products.

Figure 6: Alter NRG 1,000-TPD Plasma Gasification Reactor Tees Valley, England, United Kingdom

There were some demonstration facilities in North America that utilized PAG technology, including a 10-tpd demonstration PAG unit (manufactured by Pyrogenesis based out of Quebec, Canada). This facility processed small amounts of manually separated MSW from the Hurlburt Field Air Force Base in Florida. That demonstration facility has since been shut down. However, Pyrogenesis continues to manufacture their plasma torches and has constructed PAG waste-processing systems for onboard ship waste for the U.S. Navy, specifically the U.S.S. Gerald Ford, and for commercial cruise lines.

2.1.4 Pyrolysis

Pyrolysis technologies are closely related to gasification, and some facilities could fall into either technology category depending on how they are operated. Pyrolysis is the process of heating material to high temperatures (700 to 1,500°F) in an oxygen-free environment and driving off the volatile hydrocarbons to produce a combustible gas and liquid product (i.e., pyrolytic oils). The remaining fixed carbon forms a carbon-rich solid residue with the remaining ash and metal materials. This is similar to the process to produce coke from coal or charcoal from wood. The feedstock used in pyrolysis technologies has typically been more homogeneous than mixed municipal waste, using materials such as coal, biomass (woody wastes), or even waste tires. Torrefaction is a similar pyrolytic process, most often used with wood or biomass, that has been proposed for some facility designs. In some pyrolysis operations, pre-processing of mixed MSW has been used to obtain RDF, a relatively more homogeneous feedstock, as the primary or another feedstock for the pyrolysis facility.

Similar to gasification, the pyrolysis process can be designed to optimize the production of gases or liquids. A pilot project shown in Figure 7 is under development by Ways2H in Kern County, California. It uses a pyrolysis technology to generate a syngas that is then further refined in a waste-to-fuels project (discussed below) to generate hydrogen. For other pyrolysis facilities, syngas can be produced and used as fuel in boilers or, theoretically, in internal combustion units or gas turbines, provided that the gas is adequately cleaned. As discussed, the pyrolysis process is performed in an air- or oxygen-free environment. Therefore, the system must usually have a complex design and control system to prevent air or oxygen from intruding into the process, or a provision must be incorporated into the design to purge air from the reaction chamber. However, some pyrolysis processes allow very small amounts of air/oxygen into the system. This allows the feedstock to combust partially and supplement the heating process. Other designs may use some or all of the volatile gases to heat the feedstock. This drives off more gases and liquids and produces the fixed carbon char.

Figure 7: Ways2H Pyrolysis Facility Kern County, California

Source: Photo courtesy of Ways2H

Air emissions from pyrolysis systems are primarily those discharged from combustion of the producer gas or syngas (and possibly char). The treatment of syngas produced from MSW pyrolytic processing for use in energy conversion equipment and emissions control of syngas constituents has little history but is similar to the gasification process described above. Facilities using the pyrolytic oil and other products as fuel could have some of the same air emissions issues as direct combustion. Less SO_x might be generated in the gas or oil because most of the sulfur is expected to stay with the char. However, the sulfur could be released to form SO_x if the char is combusted. HCl would also need to be addressed in the exhaust gases. Units that heat the feedstock in an oxygen-deficient environment would produce fewer emissions. Mercury would be expected to be largely driven off with the gas and the gas combustion device exhaust would have to be addressed. Other metals and particulate could remain with the char and could largely be separated from the char prior to combustion with a suitable processing system. These emissions can theoretically be controlled using modern air pollution control devices to meet local, state, and national regulatory standards.

2.2 Biological Technologies

Biological technologies are designed to use bacteria as part of the technology employed to consume the putrescible content of feedstock. This typically occurs in low-temperature environments employing either aerobic bacteria or anaerobic bacteria. The volatile solids contained in the waste are consumed by the bacteria and converted to carbon dioxide (for aerobic processes) or a blend of methane, alcohols, carbon dioxide, and other gases (for anaerobic processes). Aerobic processes are exothermic and, if managed properly, produce enough excess heat to kill pathogens contained in feedstock. Anaerobic processes typically require heat and may require subsequent processes to kill pathogens in feedstock.

2.2.1 Aerobic Composting

Aerobic composting has been employed successfully on source-separated organics such as food waste, yard/agricultural waste, and wastewater biosolids. Some facilities are permitted and designed to accept compostable paper and plastic, and some operations have attempted to process other compostable solid waste. Aerobic composting can include a number of different processes. The two most common are aerobic windrow composting, also called turned windrow composting (see Figure 8), and forced aerated static pile composting. Windrow-style composting is the most commonly used process in the U.S., treating predominantly yard/agricultural waste, and is usually conducted outdoors. Forced aerated static pile composting is typically constrained to higher quantities of putrescible material, such as food waste or biosolids, and is often covered or indoors. However, some forced aerated static pile composting is conducted outdoors and uses biofiltration to minimize odor emissions. Aerated static pile composting can also include a variety of cover systems, including specially designed tarps or fabric covers, organic covers such as finished compost, or a specially equipped bag system to contain the materials.

Figure 8: Example of a Windrow Aerobic Composting Facility

In windrow composting, the materials (generally green material) are placed in elongated piles called windrows. The windrows are aerated naturally through a “chimney effect” or by mechanically turning the piles with a machine or forced aeration, which improves porosity. Usually, a bulking agent such as wood chips or other green waste is used to allow proper air flow through the pile to help prevent pockets of the material from becoming oxygen deficient and the composting process from becoming a localized, odiferous anaerobic process. Frequent pile turning introduces oxygen, accelerates physical degradation of feedstocks, and provides an opportunity to adjust the moisture content and temperature to the optimum levels. This technology can be particularly odorous if food waste or other MSW is included in the feedstock. The average time required for active composting is 8 to 12 weeks for windrowing, but bag and static pile composting (see Figure 9) can achieve faster composting if managed carefully.

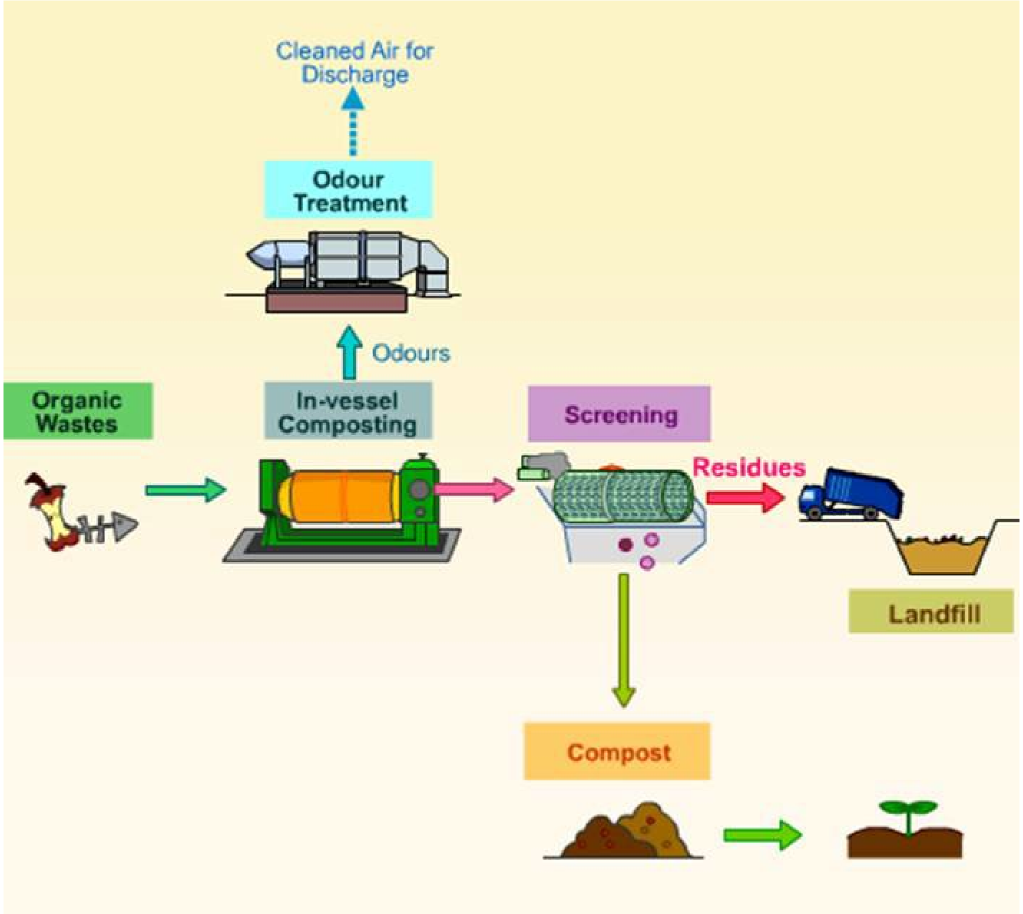
Figure 9: Example of a Fabric-Covered Aerobic Static Composting Facility, Issaquah, Washington

The aerated composting process refers to any of several systems used to biodegrade organic material without physical manipulation during primary composting. It may occur in windrows, bunkers, or mass beds and be open, covered, or in closed containers (in-vessel). Figure 10 shows an aerated static pile operation located in a covered setting and Figure 11 shows a bunker arrangement. Figure 12 shows a schematic flow diagram for an in-vessel composting system. The steps required for in-vessel composting are similar to those for other processes. In an aerated static pile composting technology, fresh air is either forced into the pile or drawn from the pile to maintain high levels of oxygen. This process accelerates the bacterial consumption of the organic material. Without the added fresh air, the denser putrescible material would naturally default to an anaerobic condition and lose aerobic bacteria. This method is suited to producing large volumes of compost in relatively smaller areas. This technology can be particularly odorous if the composting pile is allowed to have pockets of anaerobic activity. The blended mixture is usually placed on perforated piping or trenches, providing air circulation for controlled aeration. Moisture levels are managed, and material temperatures are monitored for best operation.

Figure 10: Example of a Covered Aerobic Static Composting Facility, Olympia, Washington

Figure 11: Example of a Bunker Aerobic Static Composting Facility, Stanwood, Washington

Figure 12: Example of a Windrow Aerobic Composting Facility



In negatively aeriated types of aerated compost processes, a series of perforated pipes draws air down through the windrows to an air collection manifold that runs under the windrows. The compost air can be drawn through the compost using a blower system that then pushes the air through a biofilter that acts as an emission and odor control system. Alternatively, in positive aerated systems, air can be injected into the windrows to maintain proper oxygen levels. The key in either of these systems is the appropriate use of best management practices that include the initial mix of putrescible material and bulking material (typically mulch or chipped wood) in the correct proportions to ensure the porosity and moisture content needed to maintain proper aerobic bacterial health throughout the process.

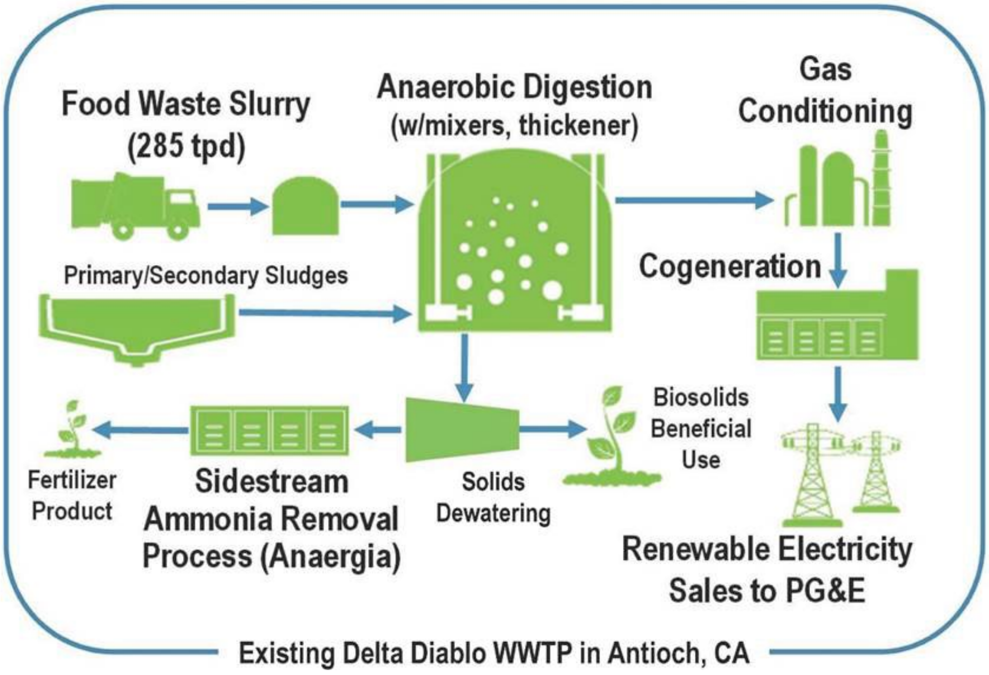
In-vessel food waste aerobic composting can also take place in highly controlled, automated equipment using a combination of agitation and temperature/moisture control to convert food scraps into compost in just a few days. Current models on the market have modest capacity. Larger units are able to process up to 1.5 tpd. This technology is most efficient for use with small food waste generators such as schools, hotels/conference centers, malls/food courts, cruise ships, hospitals, amusement parks, and sports stadiums. Some larger facilities use bags or other enclosures. Managing odors is a key concern.

Compostable paper and compostable plastic materials in the compost are often a challenge. While many of materials can eventually break down under ideal time and temperature conditions, most commercial compost facilities do not successfully accomplish this in a single process. Often these materials require additional screening processes to remove them from the final compost and either return them to the compost system for additional biological degradation or dispose of them as a residue. Also, it is difficult to differentiate between compostable and non-compostable plastics. This results in an abundance of non-compostable materials at the end of the compost process. Facilities that have accepted post-consumer food waste with compostable service ware, or other MSW materials, have had to install robust screening/cleanup measures to remove glass, plastic, metal, and other foreign materials from the compost products. These facilities often have operational issues, such as odor generation, and have had difficulty producing marketable products. Finally, composters attempt to produce the highest quality compost possible to secure the best price for their compost. The highest quality compost is certified organic compost. However, the presence of foreign materials that derive from non-compostable feedstocks will prevent the compost from obtaining certified organic compost grades.

2.2.2 Anaerobic Digestion

Anaerobic digestion (AD) is commonly used to treat wastewater biosolids and industrial/agricultural wastewater. It has also been used to treat the organic fraction of the MSW waste stream, such as food wastes and, in a few cases, additional portions of the MSW waste stream. A representative flow diagram for the Delta Diablo Wastewater Treatment Plant (WWTP) AD system is shown in Figure 13. The processes that mechanically separate the organic fraction of MSW for use in an AD process were first employed in the 1980s under the term “MBT.” A few facilities were developed in the U.S. using these AD and MBT technologies, but they ceased to operate years ago due mostly to a variety of technical and financial issues. However, evolution of the technology in parts of Europe, particularly in Germany, Spain, France, Italy, and the United Kingdom, has renewed interest in this technology in North America. AD facilities using source-separated organics, and even in a few cases mixed MSW, are successfully operating in Europe due to landfill ban policies, high tipping fees, and high prices paid for energy. In parts of California, Canada, and more recently in other parts of the U.S., processing food and source-separated organic waste streams with the use of AD in combination with aerobic composting to bio-stabilize the process residue has been developed on a commercial scale.

Figure 13: Typical Flow Diagram for an AD Plant, Delta Diablo WWTP, California



Source: Courtesy of Delta Diablo WWTP

The attraction of using an AD process is that the anaerobic digestion of material produces a methane-rich biogas that can be refined into a variety of beneficial fuels including renewable natural gas and compressed natural gas. It can also be used in low-grade conditions to fuel an engine generator. The AD process occurs when organic matter is decomposed using bacteria in the absence of oxygen. By consuming the organic materials, the bacteria produce a biogas (primarily methane and carbon dioxide). Feedstocks for AD vary according to the type of technology but, in broad terms, could include MSW-derived organics, manure, food waste, grass clippings, yard waste, brush, and wastewater treatment plant biosolids. Biologically inert materials that might be contained in the digestion feedstock, such as metals, glass, and plastics, are undesirable and considered contamination, and either must be removed prior to digestion (for wet type systems) or be screened out during or after digestion (for dry type systems). If not managed properly, the gases produced by an AD system are highly odorous and explosive. Since the AD process occurs inside a vessel, odors from these types of facilities are typically attributed to mismanagement of either the arriving feedstock or the residual digestate that has not been returned to an aerobic phase. Both of these systems should be included in a properly designed and operating AD facility. Also, with the high levels of proteins in food waste, the formation of odorous trace gases, such as hydrogen sulfide (H_2S), have been problematic for mixed MSW systems. Again, these gases can and should be managed within the gas management system of a properly designed AD facility.

There are several factors that influence AD system design and performance. Some of these factors include the concentration and composition of nutrients in the feedstock, temperature of the digesting mass, retention time of the material in the reactor, pH, acid concentration, and oxygen level.

Three basic approaches are used for AD systems based largely on the nature of the feedstocks:

- Wet low solids for dilute feedstock materials with very little to no contamination
- High solids for thick but pumpable materials that contain some contamination
- Dry or stacked for stackable feedstock blends with higher levels of contamination

Wet low-solids AD systems, as shown in Figure 14 and Figure 15, have a more dilute process that requires careful pre-processing of food waste and other feedstocks to remove any grit and other contaminants. The wet low-solids systems can include a WWTP type, in which case it could be a co-digestion system that includes both biosolids and dilute putrescible (food waste or similar) material. Generally, this is a large, tank-based system with a mixing system included in the process.

Figure 14: Low-Solids AD Plant, Sacramento, California

Figure 15: Low-Solids (Publicly Owned Treatment Works) AD Plant, Renton, Washington

High solids AD systems use a vessel designed for higher viscosity, or thicker material, using a plug flow or similar process. They may be horizontal, as shown in Figure 16, or vertical tank arrangements, as shown in Figure 17 and Figure 18, and can accept a more diverse feedstock including some level of contamination. However, they typically require some level of pre-processing to manage the material. Further compost post-processing is required for this design.

Figure 16: High Solids Horizontal AD Plant, San Luis Obispo, California

Source: Photo courtesy of Hitachi Zosen Inova

Figure 17: High Solids AD Plant, Perris, California

Source: Photo courtesy of CRR

Figure 18: Vertical High Solids AD Plant, Perris, California

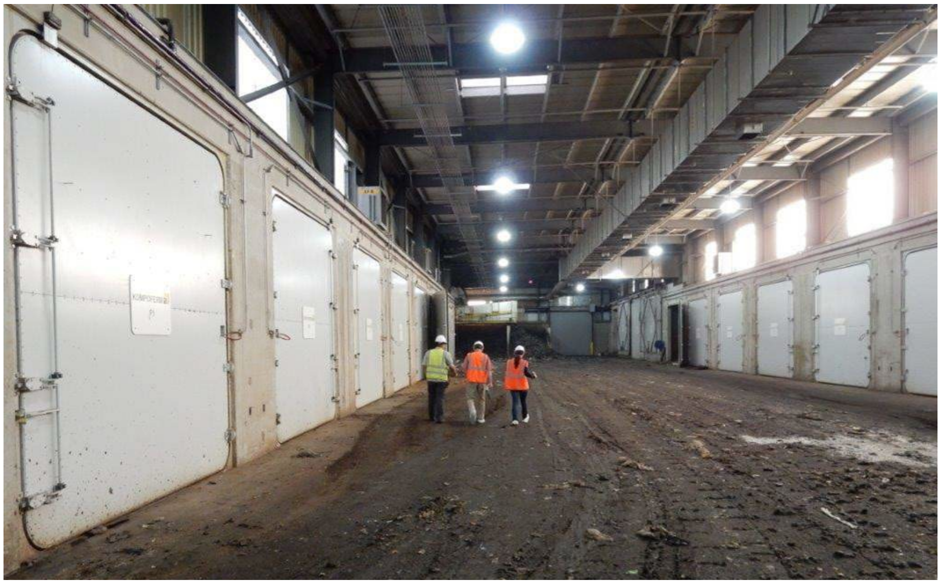
Source: Photo courtesy of CRR

Dry or stackable AD systems are designed to treat material that remains stationary throughout the digestion process. These systems use enclosed tunnels or bunkers where the feedstock is placed for several weeks, or they use percolate bunkers to stack and store drier feedstock for fermentation, as shown in Figure 19 and Figure 20. The feedstock must be somewhat porous and have a higher solids content so it can be stacked and enable the percolate to drain through the media. Consequently, yard/green waste is often included as a feedstock in this type of system. The tunnel or bunker is oriented horizontally. Biologically rich water is sprayed on the material and, after percolating through the material, is collected and recycled through the feedstock controlling moisture levels. The resultant digestate requires post-processing to convert from an anaerobic to an aerobic condition.

Figure 19: Zero Waste Energy Development Co. AD Plant, San Jose, California

Source: Photo courtesy of ZWED, San Jose CA

Figure 20: Interior of Zero Waste Energy Development Co. AD Plant, San Jose, California



Source: Photo courtesy of ZWED, San Jose CA

The Drake Water Reclamation Facility (DWRF) in the City of Fort Collins, Colorado currently uses AD to convert volatile organic solids from wastewater into a biogas that is used to heat the facility. A multi-year pilot project experimented with introducing source-separated organics directly into its biodigesters to increase biogas output. DWRF has designed and partially funded a co-generation system that will convert biogas into electricity—dependent on increased throughput of food scraps as feedstock. There are other municipal wastewater treatment plants in the county that may be a resource in developing similar AD facilities that convert diverted food waste organics to energy.

2.2.3 Mechanical Biological Treatment

As described above, MBT is a composting and materials recovery variation that incorporates a multi-stage mechanical and biological treatment process. In North America, MBT is sometimes referred to as mixed waste processing with organics recovery, but the approach and desired end products are generally the same. This technology is designed to process a fully mixed MSW stream. It is an effective waste-management method and can be built in various sizes. However, while there are a number of facilities in the Europe, the technology has not caught on well in the U.S.

The order of mechanical separating, shredding, and composting can vary. Different system suppliers offer unique arrangements, but the processes generally use the steps described below. Materials derived from the process usually include marketable metals, glass, containers, and other recyclables. Some processes may have the ability to recover select paper products when economics favor recycling.

The biological stage includes a digestion step in an enclosed vessel. This digestion generates a biogas that may be used to produce energy. In addition, the heat produced dries the feedstock, thereby making it ready for processing into an RDF product. Limited composting is used to break down MSW and dry the fuel. The biological process also generates heat, which naturally reduces moisture. Moisture level controls may be used to manage this stage. In most cases, the digestion step is not allowed to progress as long or complete as an AD system, but rather allows for easier feedstock breakdown. As with other composting and digestion systems, the process must be designed to manage potential odor issues.

RDF produced by an MBT process can either be landfilled or converted into energy via a thermal conversion process. RDF is then available as a solid fuel substitute for coal, wood, or other fuels at cement kilns or other industrial solid fuel facilities. In Europe, it is common for RDF and the residue produced by an MBT process to be fired directly in a boiler at a traditional WTE combustion facility or sold directly to a third party (e.g., cement kiln). If no fuel markets are available, the product could be further composted to render the material inert for landfilling. Consequently, similar to RDF, the MBT process produces compost and fuel products that are dependent on the sale of that product for economic viability. Since the compost is produced from mixed waste, the quality is low, the potential for beneficial use is limited, and it usually must be landfilled. One facility is reported to be in operation in Martinsburg, West Virginia. It is reported to provide its fuel product to a cement kiln, but limited information is available regarding the facility's operational performance.

In 2019, Enstorga, an Italy-based provider of MBT technology, started commercial operations of the HEBioT MBT Facility in Martinsburg, West Virginia. The facility is claimed to be able to recover biomass, plastics, and other carbon-based materials from MSW, compost the materials, and then convert them into a solid recovered fuel (SRF) that is used by a nearby cement manufacturer. Other recyclable commodities found in the MSW stream, such as metals and glass, are placed in the local municipality recycling stream to be recycled properly.

2.3 Chemical Technologies

Chemical technologies are designed to use physical chemistry processes as part of the technology employed to break down or transform various components of the processed waste infeed into building blocks that can be used for chemical feedstock, transportation fuels, or thermal energy. The potential value in these technologies is the possibility of producing transportation fuels such as diesel fuel, ethanol, or kerosene and industrial chemicals, which are usually much more valuable than the thermal energy produced that can only be turned into electricity or steam. In some cases, oil refineries may be willing to buy the fuels to blend with their fuels. Solvents (including water or potentially other solvents such as alcohol, acids, and caustic solutions), catalysts, and heat may be used as part of the chemical process to break down wastes into usable materials. Thermal depolymerization uses heat and pressure to break down hydrocarbon molecules. These processes may require emission controls for certain pollutants or have certain process residual wastes that may require management.

The feedstock for these processes usually requires extensive presorting and preparation to minimize undesirable materials and contamination. In many cases, chemical technologies are combined with mechanical, thermal, and/or biological technologies to begin the transformation process to the desired products. The other technologies are used to clean, size, sort, produce, or otherwise provide the input materials for the final chemical process to produce the desired products. Chemical technologies may address only certain types of waste materials, such as cellulosic wastes or plastics, oils, and grease, and the other technologies may be used to make the feedstock for the chemical process. Some processes may use only certain types of plastics because other types, such as polyvinyl chloride (PVC) or polyethylene terephthalate (PET), may not be suitable for the process. Sometimes multiple chemical processing steps may be necessary to produce the desired products. Long-chain molecules, such as waxes or synthetic crude oil, formed first as an intermediate product, may then crack or break additional chemical bonds into shorter molecules to form products such as diesel fuel or alcohols that are more valuable. Alternatively, desired chemicals such as methanol or ethanol may be built up from syngas first produced by a thermal reaction or other process.

2.3.1 Hydrolysis

There is much interest and development in cellulosic ethanol technology, which aims to move from corn-based ethanol production to the use of more abundant cellulosic materials. Hydrolysis is part of that development. Hydrolysis is a solvolytic reaction. Solvolysis is a chemical reaction that uses a solvent such as alcohol or water. The solvent breaks down material at elevated temperatures or in association with strong acids or bases. The hydrolysis process involves the reaction of water and cellulose fractions in a feedstock (e.g., paper, yard waste) with a strong acid (e.g., sulfuric acid) to produce sugars. Next, these sugars are fermented to produce an organic alcohol. This alcohol is then distilled to produce a fuel-grade ethanol solution that can be burned in energy conversion devices such as heaters and engines.

Hydrolysis is a multi-step process that includes four major steps: pre-treatment, hydrolysis, fermentation, and distillation. The pre-treatment step for MSW includes separating the feedstock stream as necessary to remove any inorganic/inert materials (e.g., glass, plastic, metal, rock) from the organic materials (e.g., yard waste, food waste, paper). Feedstock materials that are appropriate for hydrolysis/fermentation of the MSW cellulosic components include wood, green waste, and paper. This process does not handle or convert mixed MSW directly and is best suited for clean, source-separated cellulosic waste components. The organic material is shredded to reduce the size and to make the feedstock more homogenous. The shredded organic material is placed into a reactor where it is introduced to the acid catalyst, and the cellulose in the organic material is converted into simple sugars. These sugars are fermented and converted into an organic alcohol. The organic alcohol is then distilled into fuel-grade ethanol. The by-products from this process are carbon dioxide (from the fermentation step), gypsum (from the hydrolysis step), and lignin (non-cellulose material from the hydrolysis step). Since the acid acts only as a catalyst, it can usually be extracted and recycled back into the process.

2.3.2 Catalytic and Thermal Depolymerization

The depolymerization, or cracking, process converts long-chain hydrocarbon polymers present in some waste materials into intermediate products that can be processed into fuels such as diesel and gasoline. Pressure and heat are used to decompose long-chain hydrogen, oxygen, and carbon polymers into shorter chains of petroleum-like feedstock. This process is somewhat similar to the process used to convert crude oil into usable products, including the use of distillation to segregate the desired hydrocarbon liquids (such as diesel fuel). The typical feedstocks proposed for depolymerization are plastics, waste oils, grease, and offal (i.e., processed animal soft tissue), although some of the technology vendors are claiming that this technology can theoretically use MSW and biomass as feedstocks.

In some cases, plastics may be divided by classification. This will separate certain types of plastics that are not as useful with an economic decision regarding which materials are used as feedstock and which may be sold in traditional recycling markets. Generally, PET (or plastic type No. 1) is less useful, and PVC (or plastic type

No. 3) is generally not suitable for the depolymerization processes and must be separated from suitable feedstock. High-density polyethylene (HDPE or plastic type No. 2) is suitable for depolymerization. However, it may be more valuable recycled as a No. 2 plastic and not mixed with other types of plastics for fuel production. These depolymerization technologies have not been shown to be feasible except on a small scale.

There are two depolymerization methods that can be used to convert organic materials into fuel: thermal and catalytic. Thermal depolymerization utilizes temperature (temperature ranges from 1,000 to 1,400°F) and pressure to crack the large hydrocarbon molecules within the feedstock. These processes are similar to pyrolytic processes but are usually applied to a more refined or pure plastic feedstock and not mixed waste. The plastics must be adequately cleaned and purified to reduce contamination rates from higher levels found in plastic feedstocks (approximately 10 to 25 percent contamination) to levels suitable for processing (sometimes less than 5 percent contamination). Once the hydrocarbon molecules are broken into shorter chains, additional refining steps are required to separate fixed carbon and lighter molecules to convert the heavier molecules into commercial grade diesel. The high temperature and additional refining steps in the thermal process require a significant amount of energy compared to the catalytic depolymerization approach. There are some thermal pilot scale plants in development that are using pyrolytic or gasification processes on plastic wastes to produce a fuel or hydrogen. However, the energy balance data for thermal depolymerization of waste-derived organic materials are lacking and are not fully developed regarding commercial scale processing.

The catalytic depolymerization process uses lower temperatures (ranging from 500 to 700°F) and lower pressures than thermal depolymerization. In order to achieve adequate product yields and qualities at the lower temperatures and pressures, a catalyst is employed to aid in breaking down or cracking the large molecules efficiently. Zeolite, silica-alumina, and bauxite are common catalysts used in the process. In a catalytic depolymerization process, the plastics, synthetic-fiber components, and water in the feedstock react with a catalyst under pressure and heat to produce a crude oil. This crude oil can then be distilled to produce a synthetic gasoline or fuel-grade diesel. Some technology vendors claim to meet diesel fuel or other fuel standards suitable for use in commercial vehicles, as discussed below.

2.3.3 Waste-to-Fuel Technologies

Waste-to-fuel technologies typically involve four main steps:

- Pre-processing and preparation of the feedstock material (e.g., woody biomass or MSW);
- Converting the feedstock to generate a syngas through a thermal conversion process (e.g. gasification or another technology);
- Cleaning and conditioning the syngas of impurities and other contaminants; and

- Passing the syngas through a catalytic process, such as an FT process to synthesize a liquid fuel.

Refer to Figure 7 above for an example of a Ways2H's pyrolytic waste-to-hydrogen pilot project. The use of woody biomass and some agricultural wastes as feedstock for these technologies has a long-term operating track record. There are also some demonstration/pilot projects that are attempting to use MSW or other feedstocks, which are described in more detail below. However, the long-term operating and financial viability of using an MSW feedstock to produce a liquid fuel is still unknown.

The waste-to-fuel process for mixed MSW starts with a sophisticated processing system. Generally, the MSW is sorted to remove and recover the metals, glass, inorganic materials, other undesirable materials, and select traditional recyclables. Depending on the downstream processing system needs, the sorting process may selectively separate paper- and cellulose-containing materials and select plastics, as shown in Figure 21, or may use both types of materials. The selected fuel material is generally shredded for easier handling and to develop a more uniform feedstock. The more uniform feedstock simplifies downstream processing issues.

Figure 21: Plastics to Fuels Demonstration Project

Once a relatively uniform feedstock is produced, there are several proposed methodologies to convert MSW into fuels. First, the majority of MSW-to-fuel technologies require a process that generates a syngas, typically a thermal conversion process such as gasification or pyrolysis. The next and most important step in this process is to take the syngas produced and clean it to remove impurities (e.g., tars, hydrocarbons, contaminants) that can impact the catalytic process. The syngas has a lower Btu (energy) content compared to natural gas, and the downstream process may require water removal to concentrate the hydrogen and carbon monoxide.

The next step involves a catalytic process, such as an FT-type process, that converts the syngas into a liquid fuel. The FT process is defined as a series of chemical reactions that use a metal-based catalyst (cobalt, iron, or others) to convert a mixture of carbon monoxide, hydrogen, and sometimes steam into liquid hydrocarbons under elevated and controlled temperature and pressure conditions. The FT process has been around for almost 100 years and is used mostly to convert coal, biomass, or methane into synthetic liquid fuels. The purity of the syngas used can be critical to the success of the FT process, which makes syngas produced from MSW gasification challenging because of the contaminants present in the MSW feedstock and the relatively low ratios of H_2 to CO. The chemical reactions produce a variety of hydrocarbon molecules, with the more useful reactions producing alkanes. Most of the alkanes produced tend to be straight chain, which are suitable as diesel fuel. Use of the proper catalyst in the FT process is essential to garner the highest quality fuel while not deteriorating the catalyst. In this technical industry, there are many forms of catalysts including cobalt and ferrous-based. Syngas from MSW gasification is having the greatest issues in this area because of the contaminants in the MSW syngas and the low of ratios of H_2 to CO. Even with the extensive waste processing, the small variations in the gases produced during the FT process may cause disruptions.

The FT process is usually followed by a hydrocracking process. Hydrocracking is required to break up the long-chained hydrocarbons. The long-chained hydrocarbons are waxes, which are solid at room temperature. Therefore, to produce liquid transportation fuels, it is usually necessary to crack some of the FT process products.

As mentioned, FT process is one of the most popular types of chemical catalytic processes used to synthesize syngas into a liquid fuel. In addition to FT synthesis, there are methanol synthesis, mixed alcohol synthesis, and syngas fermentation. Each process features different reaction pressures and temperatures, requires different syngas compositions, and uses different catalysts. Alternatives to the FT process include a bio-catalytic process where biological organisms are used to break down the elemental components in the syngas into a biofuel. The Indian River Bioenergy Facility in Vero Beach, Florida, employed this technology to convert mostly agricultural wastes into ethanol, but this facility is no longer operating.

Feedstock preparation, gasification, syngas cleanup, and fuel synthesis are commercially viable using select feedstock materials such as biomass, coal, and petroleum-based materials. However, the catalysts and FT process used to produce the biofuels are very sensitive to the quality and composition of the syngas produced by the thermal/gasification component of these technologies. Using MSW or other heterogenous and mixed feedstocks in these systems is still in the development or demonstration stage.

Generating liquid fuels from waste is an evolving technology. The use of biomass, organic wastes, and plastics as feedstocks appear to be advancing in demonstration/pilot projects with a few projects moving toward commercialization. However, the use of a mixed MSW feedstock is still being tested in laboratories and demonstration/pilot projects. Some examples of commercial-scale waste-to-fuel technologies that are in commercial development include the Enerkem, Fulcrum Bioenergy, and INEOS Biofuel technologies. Since approximately 2016 Enerkem Alberta Biofuels in Edmonton, Alberta, Canada, has operated a 10-million-gallons-per-year methanol facility designed to help Edmonton reach a 90 percent MSW diversion goal by accepting up to 100,000 metric tons of MSW (the city already diverts 60 percent of the MSW stream). The Enerkem facility, shown in Figure 22, is a commercial-scale waste-to-fuel facility. The Enerkem facility utilizes an MSW gasification-to-liquid fuels technology that uses an FT-type catalytic process to generate liquid methanol and ethanol on a commercial scale.

In 2022, Fulcrum BioEnergy developed the Sierra BioFuels Plant outside of Reno, Nevada. This facility uses combination of gasification and FT process and began production of renewable transportation fuels in 2022. Fulcrum BioEnergy is also planning similar facilities in the U.S. and United Kingdom.

Figure 22: Enerkem Alberta Biofuels Facility, Edmonton, Alberta, Canada

Source: Photo Curtesy of Enerkem

Ineos Biofuels developed the Indian River Biofuels Facility (IRBF), a waste-to-fuel technology facility located in Vero Beach, Florida (see Figure 23). This 300-tpd IRBF (two units producing 150 tpd each) facility cost approximately $130 million and started operations in late 2012 using woody biomass wastes as a feedstock. The technology was designed to use a thermal gasification process to generate a syngas that was then passed through a fermentation reactor where biological organisms converted the hydrogen and CO in the syngas directly to ethanol. IRBF is permitted to receive waste, but to HDR's knowledge it never processed any MSW feedstocks. IBRF had some operational issues and challenges since startup, particularly with certain contaminants in the syngas that affected or killed off the biological organisms and eventually resulted in the facility being taken offline.

Figure 23: Indian River Biofuels Facility in Vero Beach, Florida

2.4 Mechanical Technologies

Mechanical technologies use equipment and external heat from steam or hot air (not heat produced from combustion or partial oxidation of the waste feedstock) to divide waste into usable products and residue. Most processes produce ancillary products, including recyclables, that can be marketed like those produced from a materials recovery facility (MRF), or the process may start with MRF residual materials as the feedstock. The arrangement of the equipment and overall separation processes can vary widely by facility and produce a wide range of output products. Wastes may be subdivided into plastics, paper (fiber), metals, glass, and other inert materials. Some processes may produce a low-grade cellulose product that can be used for cardboard production or for thermal, certain chemical, and biological processes. Feedstock may be cleaned to reduce chlorine content and otherwise processed to improve its fuel properties. Typically, a fuel or feedstock is produced that is designed to be used by another process or another facility, potentially to offset other solid fossil fuels. Often the ultimate fuel use facility is not part of the fuel production facility and may likely be an existing cement kiln or solid fuel boiler that is willing to contract for the fuel produced to offset coal or other fossil fuels. If a suitable use for the waste fuel is not identified, the fuel may require landfilling, so a long-term fuel supply contract is usually necessary for a viable operation that pays for the fuel production operating and maintenance costs. Process residues are generally produced that, in most cases, must be landfilled.

2.4.1 Autoclave/Steam Classification

Autoclaving is classified as a mechanical process that uses heat and pressure in a mechanical, rotating cylinder that can be used to separate cellulosic and organic material from other portions of the municipal solid waste stream. As an example, basic autoclave technology has been used to sterilize hospital wastes and equipment for many years.

Autoclaves used for MSW processing are large rotating vessels that have steam injected and kept at a certain temperature and pressure over a controlled period, up to 2–4 hours, to convert the MSW. Most autoclaves are currently operating in batch mode accepting between approximately 1 and 25 tons per batch (2–3 hours), although at least one facility was designed for continuous feeding. The autoclave process has the potential for a 40 to 60 percent reduction in waste volume, with the cellulose recovery having the potential to be used as feedstock for paper production, ethanol production feedstock, compost feedstock, or digester feedstock for methane production.

Similar to AD and chemical technologies, autoclaving may be best applied when it addresses only a portion of the waste stream, namely the cellulose-fiber-containing portion, which is usually 40 to 60 percent of the total MSW input stream. However, this technology can accept mixed MSW that contains a large organic fraction to be used as a front-end separation system for many of the other emerging technologies such as hydrolysis for fuel product production, gasification or pyrolysis for energy generation, anaerobic digestion for energy and compost production, and fiber recovery for the pulp/paper industry. A trommel screen is usually used after the autoclave to separate the fibrous organic materials produced from autoclaving and other materials (inorganic materials, plastics, and recyclables such as glass and metals). If the goal for the autoclaving technology is recovery for paper production, because the fibers are a mixed grade, the main product that can be produced is a lower-grade cardboard. Plastics generally will melt and form small balls of material. While the fiber and plastic portions of the MSW are lower quality, mixed-grade materials with fines are often very clean. Fines usually consist of material 2 inches in diameter or smaller that include organic material such as paper, dirt, and food particles as well as inorganics such as glass, plastics, and metals. Labels, paint, and other coatings are generally removed.

2.4.2 Mixed Waste Processing

There are several types of MRFs in operation in the U.S. and around the world. Most can be classified into two groups: those that accept and process source separated recyclables, commonly referred to as a single-stream or clean MRF, and those that take a mixed MSW stream, referred to as a mixed waste processing facility (MWPF), or dirty MRF. The purpose of this section is to describe MWPFs and their potential commercial applications. These facilities are often used to capture select materials, depending on the feedstock and established markets, and may not recover all the materials noted below. MWPF yields are usually much lower than conventional MRF yields due to the nature of the feedstock, but they can provide significant landfill diversion.

An MWPF begins with mixed solid waste from residential and/or commercial collection vehicles being off-loaded onto a tipping floor. Materials are first sorted on the floor using mobile and fixed equipment with some manual labor to remove or break up larger or bulky items such as appliances, dimensional wood, metal, and large pieces of plastics that might clog or interrupt processing system operations. Loaders or grapples then load a conveyor or surge hopper to convey the material to the sort lines and mechanical equipment for separation. In most cases, either a mechanical device or manual labor is used to open bags and containers prior to screening and sorting. Systems can be adapted to C&D wastes or certain other mixed waste materials.

Material is usually processed through multi-stage screens to separate fiber (cardboard, newspaper, and mixed paper), plastic, metal and glass containers, and small contaminants. This is usually accomplished using mechanical, optical, or pneumatic screening equipment and/or labor to separate materials into size classifications and/or lighter versus heavier materials. Fiber is usually sorted optically or by hand off elevated conveyor platforms into commodities and dropped into bunkers. Containers are processed through ferrous magnets, optical sorters, robotic sorters, hand sorting, and eddy current separators (ECS). The fines, usually less than 2 inches and consisting of dirt, rocks, broken glass, ceramics, bottle caps, and similar materials, may be further processed by magnets, ECS, and pneumatic sorting steps to recover metals, fiber, and a glass-rich stream.

Sorted material is moved from bunkers and baled (fiber, plastic, metal) or loaded directly into roll-off bins (glass, wood, scrap metal). Some MWPFs also isolate the organic fraction of the MSW stream to be used in a composting or AD process. The remaining residue material from a MWPF is shipped to a local landfill or used for another appropriate waste reduction application. The main purpose of this type of MWPF is to remove recyclable materials and organics from the mixed MSW. These types of facilities usually recover about 10 to 25 percent, although some facilities have reported recovery of up to 50 percent or more. There is a wide range of MWPF capacities operating throughout the world. The optimal capacity is between 200 and 1,500 tpd using multiple sort lines and operating additional shifts. MWPFs can have a useful operating life of 20 to 30 years if proper maintenance is provided. Many MWPFs are retrofitted throughout their life with new processing equipment, as applicable.

There have been several commercial-scale MWPFs implemented in North America. The most notable examples are in Montgomery County, Alabama; San Jose, California; and Edmonton, Alberta, Canada. It should be noted that the current downward trend in commodity pricing and acceptance of the processing approach has impacted the financial viability of some of these projects. The Montgomery County Facility went through an ownership change, with the County acquiring the facility and hiring a new operator. Numerous upgrades and modifications were made to the facility, with the current facility accepting more tradition single-stream materials, but it is capable of handling other types of feedstock such as mixed fiber, commercial, and industrial materials and has the potential to produce a fuel material. The Newby Island Resource Recovery Park in San Jose, shown in Figure 24, has infeed lines for residential single stream, commercial single stream, commercial wet recyclables, and a common container line that accepts materials from all of the other streams. Incoming material can be characterized in this manner and routed to the appropriate processing system.

Figure 24: Newby Island Resource Recovery Park, California

2.4.3 Refuse-Derived Fuel Production

An RDF processing system prepares MSW using separation, shredding, screening, air classifying, and other equipment to produce a fuel product, such as coarse shred, fluff, or pellets, for either on-site thermal processing, off-site thermal processing, or use in another conversion technology that requires a prepared feedstock. The goal of this technology is to derive a more homogeneous fuel product that can be used in specified thermal equipment or as a supplement to coal-fired power generating facilities, and even cement kilns in some cases. The fuel goes by various names but is generally categorized as RDF.

The RDF process typically results in a fuel yield in the 80 to 90 percent range (i.e., 80 to 90 percent of the incoming MSW is converted to RDF). The remaining 10 to 20 percent of the incoming waste that is not converted to RDF is composed of either recovered ferrous and nonferrous metals (1 to 5 percent) that can be sold to market, or process residue (15 to 19 percent) that must be disposed of in a landfill. In most cases, the fuel is used at the same facility where it is processed, although this does not have to be the case.

Non-recovered discards from an MRF can be processed using this technology. Facilities can range in size from several hundred tpd to more than 3,000 tpd. Recycling processes can also be built into an RDF facility, such as in a MRF or MWPF. Metals can usually be sorted and removed by magnets and ECS. In some cases, other recyclables such as cardboard, glass, or even plastic containers may be recycled. An RDF facility strives to develop a consistently sized fuel with a relatively constant heating value for thermal technologies. These facilities can employ multiple shredding stages, large trommel screens or other types of screens for sizing, several magnet stages, and possibly air separation, optical sorters, and ECS. The product would typically have a nominal particle size of 3 to 4 inches (although the sizing of final product RDF can be controlled for a specific technology), have the grit and metals largely removed, and be ready to market.

The U.S. Environmental Protection Agency (EPA) has encouraged processors to produce a Non-hazardous Secondary Material (NHSM) for use in industrial boilers or other applications that are subject to Section 112 of the Clean Air Act (CAA) as opposed to Section 129, which waste combustors must follow. The fuel must meet the requirements for NHSM as defined by the EPA in 40 Code of Federal Regulations (CFR) Section 241.3 of the CAA. These processing facilities require more processing and ongoing sampling to meet more restrictive requirements for residual chlorine content, chlorine to sulfur ratio, heating value, moisture, and ash content in the resultant fuel than are required for combustion of waste or RDF in a waste boiler. Refer to Section 5.0 for additional discussion of the NHSM program.

Many of the existing RDF combustion facilities in the U.S. (e.g., Miami-Dade, Florida; West Palm Beach, Florida; Detroit, Michigan; Honolulu, Hawaii; Norfolk, Virginia; Ames, Iowa) employ these practices to process the fuel. Some RDF facilities can be classified as shred and burn style facilities. These facilities shred the material and magnetically remove ferrous metals without removing fines. Some RDF facilities have converted to shred and burn through blanking the small holes in trommels. The purpose for this change is to reduce the overall amount of residue (fines) landfilled and simplify the fuel production process. An example of a shred and burn facility is the SEMASS facility in West Wareham, Massachusetts. This facility has recently replaced its high-speed hammermill shredders with high-torque shredders for safety and operational reasons.

There are also RDF technologies that, after removal of recyclable, bulky, and inert materials, form the remaining MSW stream into pellets or briquettes. The intended use of these pellets or briquettes varies by technology developer and regulation, but some examples include use as a supplement to coal at a conventional fossil fuel power plant or cement kiln. Some technology providers also offer the pellets for use as a soil amendment in greenhouses. However, the quality and integrity of the pellets or briquettes produced, and the willingness of the local market to accept this product, factor significantly into the economic viability of the project. A commercial-scale MSW pelletizer facility in York Region, Ontario, Canada (just north of the City of Toronto), was constructed in 2008 but was later shut down due to operating issues and limited available markets for the pellets. The WastAway facility in Morrison, Tennessee, may either produce an RDF fluff material or compress the fluff into pellets, depending on the target market.

3.0 Benefits and Obstacles

3.1 Thermal Technologies

3.1.1 Direct Combustion

Benefits of this technology are the local energy production and potential uses of its by-products, which include ferrous metals, nonferrous metals, and ash as landfill cover or as an aggregate in the construction industry. In addition, direct combustion technologies have a long history of reliable commercial-scale operation and can handle a variety of feedstocks with little to no pre-processing requirements. Developing the technology can create a number of construction jobs during the 1 to 3 years of construction and 40 to 80 permanent jobs over the life of the project. This technology generally requires a large waste stream (200,000 tons per year or more) to be economically beneficial. In addition, although the technology recycles and re-uses water on-site, it also requires a moderate use of water. However, implementing projects is difficult due to high capital and operating costs, particularly for smaller-scale facilities, and strong opposition from environmental groups due to a perception by the public that this technology is not environmentally friendly. Environmental groups often feel that emission limits are not restrictive enough and greenhouse gas emissions are not adequately addressed. The current low pricing for electricity and natural gas makes the energy produced from these technologies (steam and/or electricity) of low value. In addition, an obstacle for all technologies that produce electric power is that they would require a power purchase agreement (PPA) with KIUC. Obtaining the PPA can be a lengthy process and impose terms on the project that may be difficult to achieve. This technology produces an ash residue stream of about 10 to 30 percent by weight of the incoming waste stream; however, development efforts are underway to utilize portions of the ash stream. Volume reduction of the ash residuals is approximately 90 percent before any ash reuse, resulting in significant savings in landfill space.

3.1.2 Gasification

Gasification operators assert that one of the benefits of many gasification technologies is that very high diversion levels (above 90 percent) can be achieved because the slag is not leachable and can be sold as aggregate to industrial users. Other benefits include energy production, or a liquid fuel if the syngas produced is further cleaned and passed through a catalytic process (e.g., FT process). Potential uses of ferrous metal and ash by-products include landfill cover or as an aggregate in the construction industry. Local benefits include the creation of construction jobs during the 1 to 3 years of construction and 25 to 75 permanent jobs over the life of the project. The technology may be more suitable for small or medium-sized plants than direct combustion and has been developed most frequently in Japan and South Korea.

Theoretically, the emissions should be lower for most vendors than the emissions from direct combustion, and the vendors of this technology claim that this is true. However, to date, actual emissions from operating facilities have been difficult to obtain or verify due to the lack of commercial-scale facilities using mixed MSW in North America. Greenhouse gas emissions also are generated and while potentially lower than direct combustion, significant data is yet to be obtained to confirm this is the case. In some cases, facilities that were once defined as two-stage direct combustion may now identify as gasification processes since the primary chamber is intended to operate in a reducing environment, and burnout of gases produced is completed in a secondary chamber. The technology may have some applicability processing a specific subset of waste materials (not just MSW) such as wood waste, tires, carpet, scrap plastic, or other waste streams.

Some technologies may require extensive pre-processing, shredding, and other fuel preparation, which increases capital and operating costs. This remains one of the most difficult tasks in the process. It involves significant mechanical processing and close supervision, which greatly impacts operating costs and can account for as much as 40 percent of the total plant capital costs. The capital cost of the 220-tpd Thermiska TPS plant in Italy was approximately $170 million USD, with the RDF plant making up about $63 million (37 percent) of that cost. The current low pricing for electricity and natural gas makes the energy produced from these technologies (steam and/or electricity) of low value. Research and development by technology vendors, such as Sierra, may improve economics if production of hydrogen and other useful by-products is successfully demonstrated.

3.1.3 Plasma Arc Gasification

Similar to the gasification and pyrolysis processes, the MSW feedstock will need to be pre-processed to remove bulky waste, household hazardous waste, dirt, glass/grit, and metals to prevent these materials from forming slag and causing potential operating issues. Benefits include a claimed diversion of more than 95 percent waste from landfills, energy production, and potential use of ferrous metal by-products and the slag formed and marketed as aggregate (although no markets currently exist for this product). The slag that is produced is vitrified, locking up trace metals, and is not leachable. Vendors of this technology claim efficiencies that are higher than those of direct combustion and other gasification technologies. These higher efficiencies may be possible if a combined cycle power system is proposed; however, little operating experience and no commercial experience in North America are available for this technology. A local benefit is the creation of construction jobs during the 1 to 3 years of construction and 25 to 60 permanent jobs over the life of the project.

Vendors of this technology claim to achieve lower emissions concentrations than traditional mass burn technology. However, similar to other thermal technologies, APC emission control equipment would still be required for combustion of the syngas. These facilities generally have similar air emissions issues similar to the gasification, pyrolysis, and direct combustion technologies. Mercury and some other more volatile metals are expected be driven off with the gas and would have to be dealt with from the exhaust of the gas combustion device. It should be noted that although the technology recycles and re-uses water on-site, it requires a moderate amount of make-up water. Although there are some commercial-scale facilities operating on sorted MSW in Europe and Asia, there has been very limited commercial application using mixed MSW in North America. In the past few years, several significant setbacks occurred at facilities. In North America, the shutdown or termination of development of a nearly commercial scale facility occurred, and in England, shutdown of the largest plasma arc facility constructed to date occurred due to design and operational difficulties and costs. The 1,000 tpd, 50-megawatt Tees Valley Westinghouse Plasma Gasification Facility units in the United Kingdom (efforts to commission and test have been discontinued) each had a total capital investment of $500 million. Annual potential operating costs are unknown but are assumed to be as high, if not higher, than operating costs of other gasification technologies.

3.1.4 Pyrolysis

MSW pyrolysis has had limited operational history and no commercial success to date; therefore, there is little information regarding long-term operating experience. There are not many pyrolysis units functioning at a high level of capacity using MSW as a feedstock. Smaller projects are under development that utilize select waste streams as feedstock (e.g., non-recyclable plastics).

Benefits include a claim of over 90 percent diversion of waste from landfills, energy production, and potential uses of the by-products, if marketable. The liquid fuels produced may be of higher value and suitable for internal combustion engines and combustion turbines. Other local benefits include the creation of construction jobs during the 1 to 3 years of construction and permanent jobs over the life of the project. This figure cannot be estimated, as the technology requires additional development.

3.2 Biological Technologies

3.2.1 Aerobic Composting

Benefits include diversion of yard/green waste, potential reduction in food waste from being landfilled (program dependent), and the local production of beneficial use compost and mulch that can be used in the community. In addition, local benefits include the creation of construction jobs during the short period of construction and approximately 2–10 permanent jobs over the life of the project, depending on the size and complexity of the facility. The main drawback is the potential for creating odors, noise, and dust. This process also requires more land than AD. This can be mitigated with proper operations and facility siting (which is generally in agricultural lands away from urban development). Aerobic composting also addresses only certain segments of the waste stream. Those waste streams must be handled separately and kept free of miscellaneous trash and other contaminants.

3.2.2 Anaerobic Digestion

Benefits include diversion of putrescible waste (food, biosolids, wet organics) from landfill, production of renewable energy and or renewable fuels, and potential uses of the by-products as compost. In addition, other local benefits include the creation of construction jobs during the year or so of construction and approximately 10 to 25 permanent jobs over the life of the project, depending on the size and complexity of the facility. The biogas produced can also be cleaned and compressed into compressed natural gas for vehicles or cleaned and sold directly to a natural gas pipeline. The drawbacks of AD technology include the limitation of the technology to process only the feedstock appropriate for the technology (putrescible organics), as well as the potential for creating odors, noise, and dust. Wet systems are most sensitive to the types of waste utilized, with plug systems being somewhat more tolerable. Dry systems are able to accept a wide range of feedstocks that are generally similar to compost (stackable). All AD systems have the potential for odor problems. The management of odors, noise, and dust can be mitigated with proper operations and facility siting. However, they can be quite challenging for facilities that process a wider range of feedstock.

3.2.3 Mechanical Biological Treatment

A benefit is the post-collection separation of feedstocks to divert recyclables from landfill while preparing a feedstock for digestion and thermal consumption. Some processes may produce a fuel suitable for use in industrial boilers and cement kilns. Another benefit is the creation of construction jobs during the construction period and approximately 10 to 50 permanent jobs over the life of the project. The primary drawback is that the process must rely on the sale of the fuel product for economic viability. As much as 40–50 percent of the incoming waste stream winds up as non-digestible residue that requires processing from another thermal technology and/or landfilling. Some facilities have high capital and/or operating costs. Other operating drawbacks include the potential for creating odors, noise, and dust. This can be mitigated with proper operations and facility siting. The opening of the Entsorga HEBioT MBT facility has helped demonstrate the potential for this technology to deliver a fuel product that is commercially viable.

3.3 Chemical Technologies

3.3.1 Hydrolysis

The process of chemical hydrolysis is well established for some organic feedstocks, such as in the conversion of wood to paper pulp, but has been applied only to MSW-derived organics on a conceptual basis or has been limited to laboratory- or pilot-scale. There has been no sustained commercial application of this technology using MSW as a feedstock in North America, and little information is available from abroad.

Similarly, the environmental risks are not well defined. In addition to the environmental risks of any associated technology, there would be some emissions risks related to methane emissions or issues dealing with potential chemical spills. It is also expected that significant quantities of water and significant wastewater would be required.

Benefits include the diversion of organic waste from landfill, the production of a cellulosic ethanol that can be used as a fuel product, the creation of construction jobs during the construction period, and the creation of a certain number of permanent jobs over the life of the project. This figure cannot be estimated, as the technology requires additional development.

3.3.2 Catalytic and Thermal Depolymerization

Benefits include the diversion of plastic and oil waste from landfill, the production of an oil or fuel product that can be used as fuel (possibly a transportation fuel), the creation of construction jobs during the construction period, and the creation of a number of permanent jobs over the life of the project. This figure cannot be estimated, as the technology requires additional development. A major drawback is that the environmental risks are not well defined. Catalytic cracking could emit hydrocarbons from the process. There could also be other risks resulting from the handling of catalysts or solvents and related compounds that might be required for the process. Water and wastewater requirements are also not known.

3.3.3 Waste-to-Fuel Technologies

Given the emerging status of this technology with MSW, there is minimal information available on this technology. This is a two-step process:

- Producer gas will need to be generated through gasification or another technology, and
- The producer gas will then need to be cleaned and conditioned with the proper chemical catalytic process used to synthesize the syngas into a liquid fuel.

Benefits include the potential production of an ethanol-based fuel, the creation of construction jobs during the construction period, and the creation of a number of permanent jobs over the life of the project. Drawbacks include air emissions impacts associated with the thermal gasification and syngas conditioning processes and the possibility of being able to produce fuel only from a biomass-only feedstock. In addition, there are solid and liquid wastes associated with this technology. The current low oil pricing in the U.S. also makes the sale of the liquid fuel less valuable and may impact the financial viability of the project.

3.4 Mechanical Technologies

3.4.1 Autoclave/Steam Classification

Benefits include the potential diversion of materials from landfill, the production of cellulose and plastic products that can be used as feedstock for many of the technologies, the creation of construction jobs during the construction period, and the creation of a number of permanent jobs over the life of the project. This figure cannot be estimated, as the technology requires additional development. A drawback is that the environmental risks of autoclaving are not known. This technology could be used primarily as a front-end system to prepare materials for other processes, such as fiber recovery and thermal technologies. However, it relies on additive technology for the greatest diversion potential. Water and wastewater requirements are also not known.

3.4.2 Mixed Waste Processing

Benefits include the diversion of recyclables from landfill; the preparation of feedstock for thermal, chemical, or biological processes; the creation of construction jobs during the 1- to 2-year construction period; and the creation of approximately 20 to 60 permanent jobs, depending on the size and complexity of the project. A drawback is that environmental impacts such as noise, dust, and odor must be mitigated. The diversion rate for this technology alone is lower unless coupled with another technology for management of the non-recyclable materials. In addition, some of the commodities recovered from a MRF of this type may be more contaminated than those from a “clean” MRF. Current commodity pricing also impacts the financial viability of these projects.

3.4.3 Refuse Derived Fuel Production

Benefits include the preparation of MSW into a feedstock that is acceptable by other processes that allow them to be more effective and efficient; the removal of recyclable and reusable materials for beneficial use; the creation of construction jobs during the 1- to 2-year construction period, and the creation of approximately 10 to 100 permanent jobs, depending on the size and complexity of the project. A drawback is that RDF facilities will have some air emissions directly from the processing (dust) as well as from the combustion of the RDF (discussed in the Section 4.1).

An economic drawback of RDF is that it produces a solid fuel similar to coal. As a result, production of the RDF product presumes that a local appetite for a coal substitute is economically viable. For most plants looking for a coal substitute, the fuel produced must also achieve the requirements for an NHSM if the plant wants to be regulated under Section 112 of the CAA. To distinguish this application from RDF production, processing required for a boiler subject to Section 112 is called SRF in this report. (Refer to Section 5.0 for further discussion.) Fugitive particulates from the process must be controlled. In addition, other environmental impacts, such as noise and odor, must be mitigated. Costs for this type of facility are based primarily on the revenues garnered from sale of the RDF product.

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Appendix C

Example Letter of Interest and Summary Table of Technology Vendors

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April 6, 2022

[Name of Recipient]
[Title]
[Firm Name]
[Address]
[City, State Zip]

Subject: Letter of Interest: Waste-to-Energy Study of Feasible Technologies for Long-Term Management of Municipal Solid Waste on the Island of Kauaʻi, County of Kauaʻi

Dear [Name of Recipient],

On behalf of the County of Kauaʻi, Public Works Department, Solid Waste Division, HDR Engineering, Inc. (HDR) is forwarding this Letter of Interest to your company as an Interested Party to respond to the County regarding your proposed technology for long-term management of the County's municipal solid waste. Attached is information and requirements for reference in preparing your response.

The County respectfully requests your response be submitted by the end of business April 22, 2022, and greatly appreciates your time and attention to this subject. Please email any questions to KauaiWTEStudyInfo@hdrinc.com.

Sincerely,
HDR Engineering, Inc.

Mike Kaiser

Mike Kaiser
Sr. Project Manager
HDR

hdrinc.com

1001 Bishop StreetSuite 400Honolulu, HI 96813-3403
(808) 697-6200

LETTER OF INTEREST

WASTE-TO-ENERGY STUDY OF FEASIBLE TECHNOLOGIES FOR LONG-TERM MANAGENMENT OF MUNICIPAL SOLID WASTE

INSTRUCTIONS TO INTERESTED PARTIES

I. Introduction

The County of Kauaʻi's (County) existing Kekaha Landfill (landfill) is expected to reach its final capacity within the next 5 to 8 years, depending on if a planned lateral expansion is approved and actual disposed waste volumes. The limited disposal life of the landfill and limited ability to successfully permit a new landfill in the County within that remaining time has required the County to evaluate and possibly pursue alternative waste management solutions that could be commercially implemented on Kauaʻi before the landfill reaches final capacity. As a start to the process the County is seeking information on commercially available and viable waste-to-energy (WTE) and diversion technologies for possible long-term management of municipal solid waste (MSW) generated on the island.

The County's vision for this project is to evaluate alternative MSW WTE and diversion technologies and determine which technologies could be successfully deployed at a commercial scale and provide the "best fit" in managing the County's MSW for a minimum of 20 years.

The purpose of this Letter of Interest is to solicit feedback from Interested Parties with proven experience and/or expertise in management of MSW specific to the following requirements:

A. Capable of sorting and recycling MSW into marketable commodities.
B. Capable of sorting MSW into feedstock for WTE technologies.
C. Capable of directly converting MSW to electric power that would be consumed on Kauaʻi.
D. Capable of converting MSW to products having energy value. In this case, the products having energy value may be consumed on or exported from Kauaʻi.
E. Combinations of the above technologies.

II. Minimum Requirements

The County is requesting information for proven and scaled solid waste management technologies that meet the current standards set forth by all applicable County, State and Federal laws that govern the safe and proper operation of such facilities and is generally accepted in the Solid Waste Management Industry as a viable approach to solid waste management.

III. Evaluation Process

The County has requested the services of HDR Engineering, Inc. (HDR) to assist in coordinating, requesting, compiling and evaluating responses to the Letters of Interest. The County intends to evaluate technologies submitted in response to this Letter of Interest in a 2-step process. The first step is to request and review responses from Interested Parties and determine which types of technologies are commercially viable and meet the best interests of the County if integrated into their solid waste management system, whether as a standalone technology or combination of technologies. The second step will consist of issuing requests for additional information, as needed, to further evaluate selected technologies to formulate a best fit solution of technologies. Upon completion of step two, the County anticipates a decision can be made whether there is justification to move forward with a detailed request for technical and financial qualifications for specific technologies.

IV. Submission Requirements

On behalf of the County, HDR is requesting Interested Parties email one (1) set of the following requested support documents in searchable PDF format to the email address provided below:

KauaiWTEStudyInfo@hdrinc.com

If the attachment file size(s) limit email transmissions, multiple emails (i.e. Part 1 and Part 2) can be submitted or a cloud transfer site can be requested from HDR.

The support documents requested in response to the Letter of Interest are as follows:

A. Cover Letter: The County requests Interested Parties submit a cover letter with the firm’s contact information, including Hawai‘i-based representatives, if available.

B. Step 1: Questionnaire: The County requests Interested Parties complete and submit information about your technology as provided in the attached Step 1: Questionnaire.

V. County Reserved Rights

A. Interested Parties that respond to this Letter of Interest acknowledge that doing so is on a voluntary basis. The County accepts no liability for the costs and expenses incurred by any party in preparing a response or responses to clarification requests if needed. Each Interested Party that enters the process shall prepare the required materials and submittals at its own expense and with the express understanding that Interested Parties cannot make any claims whatsoever for reimbursement from the County for the costs and expenses associated with the process.

B. The County reserve the right to retain all information provided and to use any ideas for further development of a potential project regardless of whether the interested party's technology is selected for further development. All information provided will become the sole property of the County.

C. If any information provided contains any trade secrets that the Interested Party does not want disclosed to the public, the Interested Party shall mark that information as "trade secret." The County , however, shall not in any way be liable or responsible for the disclosure of any such information or any part thereof if disclosure is required under the Public Records Act (Government Code, Section 6250 et seq.), Hawaii Uniform Practices Act (Hawaii Revised Statutes Section 92F et seq.), or pursuant to law, or legal process. In addition, by submitting information the Interested Party agrees to save, defend, keep, bear harmless, and fully indemnify the County, its elected officials, officers, employees, agents, and volunteers from all damages, claims for damages, costs, or expenses, whether in law or in equity, that may at any time arise or be set up for not disclosing a trade secret pursuant to the Public Records Act, including those arising from or connected with the County's refusal to disclose the protectable document to any party making a request for those items.

D. Responding to this Letter of Interest does not commit the County to pursue or finalize an agreement or to pay any costs associated with the preparation of any information, nor to enter into an agreement with the Interested Party.

VI. Kauaʻi Island Utilities Cooperative Protocols

To create a manageable process for all involved, Interested Parties who respond to this Letter of Interest with a solution that involves power production are asked <u>not</u> to engage with Kauaʻi Island Utility Cooperative (KIUC) on an individual basis. The County is not requesting financial information for this step of the project. Therefore, communication with KIUC is not necessary in submitting a response.

STEP 1: QUESTIONNAIRE

I. Contact Information

A. Company name

B. Name of contact person

C. E-mail address

D. Phone number

E. Website

II. Commercial Experience:

A. Provide the date and location (i.e. State/Province and Country) of incorporation for your Company.

B. Describe the operating experience of the company principals in designing, constructing, operating, and managing proposed or similar technologies.

C. Provide information that supports your Company’s ability to execute a full-scale project on Kaua‘i.

D. Provide the number and size of facilities in operation, including the below requested information as available and/or applicable. Information can be submitted in the form of marketing and technical brochures, schematic drawings, flow diagrams and other supplemental technical information to clearly describe the technology based on the information requested, as relevant. The County is providing an estimated breakdown of the current and projected waste types and volumes on the island for reference (see Attachment 1).

E. Provide testimonials from owners or partners of current projects.

The County asks Interested Parties not to submit financial information in the form of capital costs, operating and maintenance expenses, pro forma’s, proposals, estimated power purchase agreement rates, etc. Financial analysis is not being considered in this phase of the project.

<u>Requested Information</u>

1. Technical description of the technology and/or system.
2. Commercial project location(s).
3. Commercial operation date(s).
4. Duration the facility(s) has been in operation.
5. Typical processing capacity (hourly, daily, and annual throughput of waste).
6. Characteristics of waste feedstock (describe pre-sorting if required).

7. Characteristics of actual feedstock for current operational projects.
8. Characteristics of residuals produced and volumes, including any types of wastewater or other byproducts produced from specific components or processes of the technology.
9. Generation at full capacity (steam flow, power generation, bulk fuel volumes, commodity production rate and/or other).
10. General facility arrangement requirements (i.e. covered or uncovered operations, modular components)
11. Typical land requirements.
12. Typical utility requirements.
13. Can the technology be implemented on a standalone basis?
14. Will the technology need to be co-located adjacent to a separate MSW sorting technology?
15. Characteristics of any consumable or durable goods produced and ratios of feedstocks to production volumes.

Attachment A

Waste Generation Tables

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County of Kauai Waste-to-Energy Study of Feasible Technologies
Table 1 - Waste Generation and Composition

Date: April 6, 2022

	Annual Waste Generation, Diversion & Disposal (tons)			Estimated Composition of Disposed (tons)(6)											County Flow Controlled Recyclables for Feedstock (tons)(8)				
Fiscal Year(1)	Total MSW Generated (tons)	Total Diverted Material (Tons)	Total Tons Disposed (tons)(5)	Paper (18.4%)(7)	Plastic (11.5%)(7)	Glass (2.8%)(7)	Metal (3.9%)(7)	Food (10.3%)(7)	Other Organics (18%)	Inerts and Other C&D (23.7%)(7)	Electronics and Appliances (1.7%)(7)	Household Hazardous Waste (0.07%)(7)	Special Waste (1.7%)(7)	Mixed Residual (7.3%)(7)	Paper (7.2%)(9)	Plastic (0.13%)(10)	Glass (0.74%)(11)	Green and Wood Waste (36.0%)(12)	Tires (0.25%)
2019(2)	158,659	67,593	91,066	16,756	10,473	2,550	3,552	9,380	16,392	21,583	1,548	637	1,548	6,648	4,867	88	500	24,333	169
2020(3)	156,041	68,325	87,716	16,140	10,087	2,456	3,421	9,035	15,789	20,789	1,491	614	1,491	6,403	4,919	89	506	24,597	171
2021(4)	158,054	67,963	90,091	16,577	10,360	2,523	3,514	9,279	16,216	21,352	1,532	631	1,532	6,577	4,893	88	503	24,467	170
2022	160,093	68,840	91,253	16,791	10,494	2,555	3,559	9,399	16,426	21,627	1,551	639	1,551	6,661	4,956	89	509	24,782	172
2023	162,158	69,728	92,430	17,007	10,629	2,588	3,605	9,520	16,637	21,906	1,571	647	1,571	6,747	5,020	91	516	25,102	174
2024	164,250	70,627	93,622	17,227	10,767	2,621	3,651	9,643	16,852	22,189	1,592	655	1,592	6,834	5,085	92	523	25,426	177
2025	166,369	71,539	94,830	17,449	10,905	2,655	3,698	9,768	17,069	22,475	1,612	664	1,612	6,923	5,151	93	529	25,754	179
2026	168,515	72,461	96,053	17,674	11,046	2,689	3,746	9,894	17,290	22,765	1,633	672	1,633	7,012	5,217	94	536	26,086	181
2027	170,689	73,396	97,293	17,902	11,189	2,724	3,794	10,021	17,513	23,058	1,654	681	1,654	7,102	5,285	95	543	26,423	183
2028	172,891	74,343	98,548	18,133	11,333	2,759	3,843	10,150	17,739	23,356	1,675	690	1,675	7,194	5,353	97	550	26,763	186
2029	175,121	75,302	99,819	18,367	11,479	2,795	3,893	10,281	17,967	23,657	1,697	699	1,697	7,287	5,422	98	557	27,109	188
2030	177,380	76,273	101,107	18,604	11,627	2,831	3,943	10,414	18,199	23,962	1,719	708	1,719	7,381	5,492	99	564	27,458	191
2031	179,668	77,257	102,411	18,844	11,777	2,868	3,994	10,548	18,434	24,271	1,741	717	1,741	7,476	5,563	100	572	27,813	193
2032	181,986	78,254	103,732	19,087	11,929	2,904	4,046	10,684	18,672	24,584	1,763	726	1,763	7,572	5,634	102	579	28,171	196
2033	184,333	79,263	105,070	19,333	12,083	2,942	4,098	10,822	18,913	24,902	1,786	735	1,786	7,670	5,707	103	587	28,535	198
2034	186,711	80,286	106,425	19,582	12,239	2,980	4,151	10,962	19,157	25,223	1,809	745	1,809	7,769	5,781	104	594	28,903	201
2035	189,120	81,322	107,798	19,835	12,397	3,018	4,204	11,103	19,404	25,548	1,833	755	1,833	7,869	5,855	106	602	29,276	203
2036	191,560	82,371	109,189	20,091	12,557	3,057	4,258	11,246	19,654	25,878	1,856	764	1,856	7,971	5,931	107	610	29,653	206
2037	194,031	83,433	110,597	20,350	12,719	3,097	4,313	11,392	19,908	26,212	1,880	774	1,880	8,074	6,007	108	617	30,036	209
2038	196,534	84,509	112,024	20,612	12,883	3,137	4,369	11,538	20,164	26,550	1,904	784	1,904	8,178	6,085	110	625	30,423	211
2039	199,069	85,600	113,469	20,878	13,049	3,177	4,425	11,687	20,424	26,892	1,929	794	1,929	8,283	6,163	111	633	30,816	214
2040	201,637	86,704	114,933	21,148	13,217	3,218	4,482	11,838	20,688	27,239	1,954	805	1,954	8,390	6,243	113	642	31,213	217
2041	204,238	87,822	116,416	21,420	13,388	3,260	4,540	11,991	20,955	27,591	1,979	815	1,979	8,498	6,323	114	650	31,616	220
2042	206,873	88,955	117,917	21,697	13,561	3,302	4,599	12,145	21,225	27,946	2,005	825	2,005	8,608	6,405	116	658	32,024	222
2043	209,541	90,103	119,439	21,977	13,735	3,344	4,658	12,302	21,499	28,307	2,030	836	2,030	8,719	6,487	117	667	32,437	225
2044	212,244	91,265	120,979	22,260	13,913	3,387	4,718	12,461	21,776	28,672	2,057	847	2,057	8,831	6,571	119	675	32,855	228
2045	214,982	92,442	122,540	22,547	14,092	3,431	4,779	12,622	22,057	29,042	2,083	858	2,083	8,945	6,656	120	684	33,279	231

1. Fiscal Year 2019 (July 1, 2019 - June 30 ,2020).
2. Reported by the County in 2021 Integrated Solid Waste Management Plan Update.
3. Reported by the County of Kauai.
4. Estimated based on data from 2021 ISWMP. 8.47 waste pounds per capita per day, 365 days per year, and estimated de facto population projections. Used 1.29% average annual waste increase and 43% average diversion rate.
5. Disposed at Kekaha Landfill.
6. Categories and percentages from 2017 Kauai County Waste Characterization Report.
7. Refer to Table 2 for further breakdown of waste types.
8. Flow controlled recyclable tons that the County could possibly divert as feedstock for feasible technology. Percentage of Total Diverted Materials
9. Includes cardboard and mixed paper.
10. Includes Non-HI5 plastics.
11. Includes Non-HI5 glass.
12. Includes green waste and wood pallets.

Table 5. Detailed Composition, Overall Kaua'i Countywide Waste Composition, 2016

Material	Estimated Percent	Estimated Tons	Material	Estimated Percent	Estimated Tons
Paper	**18.4%**	**15,441**	**Other Organics**	**18.0%**	**15,107**
Uncoated Corrugated Cardboard	4.4%	3,674	Leaves and Grass	4.3%	3,579
Kraft Paper Bags	1.4%	1,149	Prunings and Trimmings	1.9%	1,585
Newspaper	0.8%	629	Branches and Stumps	0.1%	64
White Ledger Paper	1.3%	1,096	Manures	0.0%	0
Mixed Paper	4.1%	3,472	Textiles	3.0%	2,525
Aseptic and Gable Top Containers	0.4%	323	Carpet	0.6%	508
Compostable Paper	4.4%	3,711	Sewage Sludge	4.8%	3,985
Non-Recyclable Paper	1.7%	1,386	Non-Recyclable Organic	3.4%	2,861
Plastic	**11.5%**	**9,595**	**Inerts and Other C&D**	**23.7%**	**19,815**
PETE Containers - HI-5	0.4%	375	Concrete	1.3%	1,072
PETE Containers - Non-HI-5	0.3%	246	Asphalt Paving	0.0%	3
HDPE Containers - HI-5	0.1%	122	Asphalt Roofing	1.9%	1,566
HDPE Containers - Non-HI-5	0.5%	430	Clean Lumber	5.0%	4,167
Plastic Containers #3-#7	1.1%	958	Treated Lumber	2.9%	2,467
Plastic Grocery and Other Merchandise Bags	0.0%	41	Other Wood Waste	6.2%	5,157
Agricultural Film Plastic	0.1%	80	Gypsum Board	3.4%	2,821
Other Clean Film	0.5%	385	Rock, Soil and Fines	1.7%	1,395
Non-Recyclable Film Plastic	4.1%	3,407	Non-Recyclable Inerts and Other	1.4%	1,166
Durable Plastic Items	1.9%	1,605			
Expanded Polystyrene Food Serviceware	0.4%	364	**Electronics and Appliances**	**1.7%**	**1,446**
Other Expanded Polystyrene	0.3%	236	Covered Electronic Devices	0.2%	138
Non-Recyclable Plastic	1.6%	1,345	Non-Covered Electronic Devices	0.5%	387
			Major Appliances	0.0%	0
Glass	**2.8%**	**2,332**	Small Appliances	1.1%	921
Glass Bottles and Containers - HI-5	0.9%	761			
Glass Bottles and Containers - Non-HI-5	1.3%	1,083	**Household Hazardous Waste (HHW)**	**0.7%**	**626**
Non-Recyclable Glass	0.6%	488	Paint	0.0%	38
			Empty Aerosol Containers	0.1%	70
Metal	**3.9%**	**3,240**	Vehicle and Equipment Fluids	0.0%	0
Tin/Steel Cans	0.5%	438	Used Oil	0.0%	2
Bi-Metal Cans HI-5	0.1%	69	Batteries	0.1%	109
Other Ferrous	1.3%	1,060	Mercury-Containing Items - Not Lamps	0.0%	0
Aluminum Cans - HI-5	0.3%	228	Lamps - Fluorescent and LED	0.0%	8
Aluminum Cans - Non-HI-5	0.1%	78	Remainder/Composite Household Hazardous	0.5%	399
Other Non-Ferrous	0.6%	530			
Remainder/Composite Metal	1.0%	838	**Special Waste**	**1.7%**	**1,415**
			Ash	0.2%	130
Food	**10.3%**	**8,635**	Treated Medical Waste	0.0%	4
Retail Packaged Food - Meat	0.5%	432	Bulky Items	0.4%	335
Retail Packaged Food - Non-Meat	2.8%	2,361	Tires	0.0%	9
Unpackaged Food - Meat	0.9%	787	Remainder/Composite Special Waste	1.1%	937
Other Packaged Food - Meat	0.6%	522			
Unpackaged Food - Non-Meat	4.3%	3,597	**Mixed Residue**	**7.3%**	**6,089**
Other Packaged Food - Non-Meat	1.1%	936	Mixed Residue	7.3%	6,089
			Totals	**100.0%**	**83,740**
			Samples	**162**	

Confidence intervals calculated at the 90% confidence level. Percentages for material types may not total 100% due to rounding.

Nakasato, Ayako

From: KauaiWTEStudyInfo
Sent: Wednesday, April 20, 2022 8:20 AM
To: [redacted]
Subject: CoK Letter of Interest - Deadline Extension

Dear [redacted]

On behalf of the County of Kauai, please accept this email notification that the deadline to submit a response has been extended to the end of business on May 2nd. The County wishes to allow additional time to prepare your response to the LOI if needed.

Sincerely,

Mike

Mike Kaiser, P.E.
Sr. Project Manager

HDR
1001 Bishop Street, Suite 400
Honolulu, HI 96813-2822
D [808.697.6252) **M** [808.425.8049]
michael.kaiser@hdrinc.com
hdrinc.com/follow-us

Study of Feasible Technologies for Long-Term Management of Municipal Solid Waste on the Island of Kauai

Table C - Summary of Vendor Technologies

Chemical & Biological Technologies

Technology Vendor Name	Technology Description	Operating Experience (No. Operational Projects/Facilities & Location)	Established, Emerging or Undeveloped	Waste Streams Processed, Diversion Potential & Limitations	Processing Throughput (TPH, TPD, TPY)	Site Requirements (Minimum Acres, Utilities, Other etc.)	Products, Electricity, Fuel, Other Commodities Produced	Presort or Waste Separation Requirements for Technology	Residuals Wastes Not Managed, Wastewater or Other Byproducts	Other Required Non-Presort Type Support Facilities	Operating, Design Build, Financial, Other	Opinion of Commercial Viability (Yes/No), Risk and Other Evaluation Discussion
Anaergia Services, LLC	Anaerobic Digestion	11 - US, 1 - CAN and 1 - Cyprus.	Established	Targeted streams: Organics polishing and high-solids AD after pre-sorting. Limits: Pre-processing required of municipal solid waste and source separated organics to remove inorganics. Diversion potential: 30%	55,000 to 300,000TPY depending on project Projects listed as both organics and MSW processing types.	Minimum site size not provided Suggested location at Lihue WWTP. Would require interconnect to KIUC grid.	RNG, electrical power, and RDF feedstock for WTE technologies. Soil amendment from organic residuals. Pre-sorting would produce other recyclable materials such as metal and glass. Example project stated 100,000 TPY produces 3.2 MW of electricity for plant use and 300,000 MBTU of pipeline RNG.	Front end MRF required for organics and other recyclables (stated by others).	Organic residuals would require drying/conditioning process for use as soil amendment. Inorganic residuals from pre-sorting processed into RDF for WTE technology. Metal and glass recycled.	Requires biogas treatment technology for pipeline RNG.	Capable of self design, build, own, operate and finance delivery approach.	Yes technology is commercially viable. Proposed AD technology is viable based on proven industry experience. Project size is scalable to meet County requirements for management of organics and biosolids (AD). Residuals require processing for use as soil amendment or would be landfilled. Would need to quantify need for soil amendment on Kauai. Require end source for RNG (limited to siting at WWTP). Technology is concentrated on limited waste stream (organics and biosolids). WWTP biosolids Requires WTE technology on island for RDF feedstock.
Bio Carbon Fuels, LLC (BCF) Partnerships proposed with The Worley Group (Worley) and Reform Earth Technologies (RET)	Pyrolysis	No operational facilities provided by BCF. Referenced a UK project that BCF will commit turnkey technology for 200 TPD feedstock project. That project is in risk analysis and financial closing phases. Referenced a South Carolina project that advanced to design pre-feed stage and received permit approvals. Several projects and various technologies listed by Worley.	Emerging	Targeted streams: Municipal solid waste, hospital waste, slaughterhouse waste, C&D waste, agricultural waste, sewage and cesspit waste, contaminated oil, oil sludge and tires. Limits: Pre-sorting required to remove metal and glass.	500 TPD	5 acres Electrical: 5 MW for 500 TPD feedstock project. Stated facility can provide own parasitic power.	Renewable diesel and Naphtha. Pre-sorting would produce other recyclable materials such as metal and glass. Feedstock to production volume ratios provided as 12.5 MM gallons of renewable diesel and 2.5M gallons of Naphtha based on 500 TPD of feedstock.	Front end MRF (minimal discussion in response).	5% by volume of ash that can be vitrified into non-leachable obsidian. 60,000 gals/week of R2 water is produced.	Waste stream must be pre-blended or homogenized into a very specific moisture set point prior to pyrolysis and condensed into renewable fuel product (BCF patented technology). RET pyrolysis technology converts feedstock from BCF technology into syngas/liquid fuel.	Requires team approach for a design, build, own, operate and finance delivery.	Yes technology is commercially viable. No commercial facility operational in US. Sorting to remove glass concrete, metal, etc. will not be 100% effective and likely result in high maintenance of system. Kauai project would be the first time the three technologies (BCF, RET and Worley) have been integrated. Technology is concentrated on single waste stream. Low diversion potential for anticipated high cost. Produces byproducts that would require landfilling or marketable end use.
Endeavour (parent company) Edged Energy and Pact Fuels Division Partnership with Pacific Current (Hawaii Electric Industries)	Pyrolysis	No plastic waste commercial facility operable in US. Agricultural and medical waste facilities operated in California, waste tires in Australia, and MSW in Aruba.	Emerging	Targeted streams: Non-recyclable plastics Limits: Mixed non-recyclable plastic (#2 through #7). PET, EPS, and ABS plastics cannot be processed/accepted.	7,000 TPY Pact P2F Reactor can process up to 1 TPH, 20 TPD and 7,000 TPY at full capacity.	Minimum of 1.5 acres required. Approximately 5,000 square feet of covered area for receiving and equipment. Standard electrical and water utilities. Would require KIUC interconnect in non-condensable gases if converted to energy.	Sulfur-free diesel fuel and other co-products (char, ash and wax). Conversion 65%-75% of mass to 5,000 GPD of fuel.	Front end MRF is needed to separate plastics.	Non-sulfur wax, ash and char (6% of mass). Listed as co-products, however, would require end uses. Non-condensable gases (20%-30%) of mass. Can be combusted for process heat and power.	None noted.	Requires team approach for a design, build, own, operate and finance delivery.	Yes technology is commercially viable. No commercial facility operational in US. Technology is concentrated on single waste stream. Low diversion potential for anticipated high cost of . Produces byproducts that would require landfilling or marketable end use.
Entsorga Inc.	Mechanical Biological Treatment	25 in-vessel composting and bio-stabilization plants. Over 32 treatment plants for kitchen waste and green waste composting in 7 countries.	Established	Targeted streams: Unsorted municipal solid waste. Diversion potential: 80% or more (with product using facility not included).	80,000 -150,000 TPY.	5 to 7 acres With utility hook-ups. State that the technology consumes 34-51 kWh per ton.	Sustainable engineered fuel (SRF) - Designated by the EPA as a "non-hazardous secondary material". Natural gas and fertilizer compost.	N/A	Refuses residuals are landfilled.	Small sorting system on the front end of its process. User for fuel or products. Landfill for residuals.	Plastic diversion goal of 100%.	Requires a user for fuel or products produced.
Gen2, LLC Co-owns Gen Tech PTD technology with Technotherm.	Pyrolysis	2 - US. No commercial facility operable yet. In design stage for project in Crawford, PA. Some site work has been completed. Shipped tested GenTech PTD1 (first generation) equipment from Africa to Stockton, CA. Pending permits to operate and commissioning. Developing a MSW to electricity plant in Ireland.	Emerging	Targeted streams: Non-recycled plastics, including HDPE, LDPE, polypropylene, and other resins. PETE plastics would be sorted for recycling. Limits: PVC requires additional equipment and would not be processed. Requires clean plastics. Diversion potential: 10% - 15%	15,000 TPY One Gen2 Tech PTD unit processes 1.72 TPH, 41.3 TPD, and produces 11,155 GPD of fuel. Crawford, PA project will convert 250 TPD of plastic to 22.7 MM GPY of fuel. One Gen Tech PTD system can convert 15,182 TPY of plastic waste to 3.46 MM GPY of clean fuel, 2.74 MM GPY of ultra low sulfur diesel, and 721,000 GPY of marine fuel. Kauai plastic volumes would produce 2.34 MM GPY of fuel in 2025.	5 - 7 acres 12,000 square foot building on 2.5 acres is optimal. Additional 2-4 acres ideal for feedstock storage. Produces sufficient energy to operate on parasitic load with supplemental solar. Requires water supply for washing equipment. Water is recycled back through system.	Ultra-low sulfur #2 diesel and marine fuel.	Sorting and separation system at the front end of project for presorted plastics. Plastics may need additional sorting and washing depending on cleanliness.	None noted.	Standalone.	Requires team approach for a design, build, own, operate and finance delivery.	Yes. GEN2 does not have a US commercial facility in operation using primary technology. Reported Stockton, CA project operational Q3, 2022. Requires relatively clean feedstock, pre-washing may be needed. Fuel types and end uses on Kauai may prove difficult. Technology is concentrated on single waste stream. Low diversion potential for anticipated high cost.
Green Waste Energy	Pyrolysis	Operating experience in South Africa (not active). Constructing a plant in the US (not commercial).	Undeveloped	Targeted streams: MSW, C&D waste, commercial and industrial waste, hospital waste, sewage and cesspool waste, oil sludge, biomass, wood. Limits: Recommend keeping organics and inorganics separate to increase output. Diversion potential: 80%.	25 TPD and 120 TPD, systems come in two sizes	Not described	Projected 5 MW of power depending Btu level of waste and whether organic and inorganic fractions of waste are separated.	System has capability to sort out unwanted waste but a primary system to perform this task should be incorporated prior to system offered.	Rejected waste and exhaust.	Standalone, but suggests having some type of preprocessing system.		Scale up/down possible with taking modules offline and online. Limited commercial experience - none with 120 tpd unit size.
Harp Renewables	Anaerobic Digestion	Claim operating experience in US, France, Belgium, Australia, UK, Germany and Ireland. No commercial facilities noted other than MBT facility which does not appear to be the suggested project. The US MBT facility recently shutdown.	Undeveloped	Targeted streams: MSW organics, agricultural wastes, animal by product, and recyclables. Diversion potential: 30% - 80% (with user of products not included).	150,000 TPY	10 acres Electrical grid connection and or a gas grid injection point.	Electricity. Composted material.	No presort requirements described.	Natural gas and composted material that can be used in soil amendment.	Technology can be implemented on a standalone basis or can be integrated with other facilities. User for fuel or products.	Claim experience with BioHiTech plant in West Virginia that Ensorga also claims.	Requires a user for fuel or products produced. No reference facility noted for anaerobic digestion.
Hoskinson Group	Gasification	Plant in Toronto (26 yrs. operation) and one decommissioned plant in Maryland noted.	Established	Targeted streams: MSW that is pretreated with their operating system, household hazardous waste, wood, tires, waste oil, and medical waste. Diversion potential: 80%.	20-2000 TPD (Modular units)	10 to 15 acres and close to a substation with adequate capacity.	Electricity.	Bulky items are removed on receiving floor. Rest of waste is shredded and process removes much of the metals, glass, and other inert materials.	Bottom ash, fly ash, blowdown boiler water, and waste removed from tipping floor.	Typically a standalone technology.		

Study of Feasible Technologies for Long-Term Management of Municipal Solid Waste on the Island of Kauai

Table C - Summary of Vendor Technologies

Chemical & Biological Technologies

Technology Vendor Name	Technology Description	Operating Experience (No. Operational Projects/Facilities & Location)	Established, Emerging or Undeveloped	Waste Streams Processed, Diversion Potential & Limitations	Processing Throughput (TPH, TPD, TPY)	Site Requirements (Minimum Acres, Utilities, Other etc.)	Products, Electricity, Fuel, Other Commodities Produced	Presort or Waste Separation Requirements for Technology	Residuals Wastes Not Managed, Wastewater or Other Byproducts	Other Required Non-Presort Type Support Facilities	Operating, Design Build, Financial, Other	Opinion of Commercial Viability (Yes/No), Risk and Other Evaluation Discussion
InnoWaCon	Mechanical Biological Treatment	1- Germany, 1 - China, and 1 - France Example projects include: Bangkok Facility: 800 TPD, France: 80,000 metric tons/year, and Germany: 100,000 metric tons/year. No US plant but commercial facilities for fuel production.	Emerging	Targeted streams: Municipal solid waste and organics. Diversion potential: 80% with user of products (not included).	80,000 TPY	Not described	MYT fuels and minerals.	Paper, packaging and glass are source separated to be recycled. Course grade minerals are already extracted and recycled at the first step .	Processed water.	User of fuel or products.		Requires a user for fuel or products produced.
Interstate Waste Technologies	Pyrolysis	1 - China and 2- Japan No US or North American commercial experience. No known or supported experience for ethanol production.	Emerging	Targeted streams: Municipal solid waste and industrial waste. Diversion potential: 80% or more	123,755 TPY (single modular unit)	15 acres Dependent on back end electricity or ethanol facililty production requirements.	Synthesis gas , mineral Granulate, an iron-copper alloy, salt, sulfur, and zinc concentrate.	No presort requirements other than removal or processing of bulky waste.	The Thermoselect Technology claims no residuals requiring landfilling. No ash is produced and no wastewater leaving facility.	Does not need to be co-located adjacent to a separate MSW sorting technology.		No US project in commercial operation. No project experience cited for the organics approach presented.
New Hope Energy Partnerships proposed with Lummus Technology, S&B Engineers and Constructors, and Bulk Handling Systems.	Pyrolysis	1 - US facility operated in Tyler, TX. Facility has been in operation for three years. Expansion in planning with completion estimated early 2024.	Emerging	Targeted streams: Non-recyclable plastics including Type 2 (HDPE), Type 4 (LDPE), Type 5 (PP), Type 6 (PS), and plastic films. Limits: Stated partnerships can process Type 1 (PETE) & Type 3 (PVC) plastics and organics. Diversion potential: 10% - 15% . Potential increase in diversion with partners for recyclable plastic and organics as noted above.	140 TPD (modular) Current Texas plant capacity is 80 TPD, with ongoing expansion to 500 TPD (early 2024). Modular units that scale at 140 TPD.	27 acres for the 420 TPD plant and 60 acres for the 1000 TPD plant. Separations/sorting, storage and distribution are scaled to project needs. The site also requires basic utility hook-ups and natural gas.	As a percent of processed feedstock, C3-C5 gas cuts (14%) , light naphtha (19%), ULDF (36%), heavy oil (16%), bitumen(4%) and fuel gas (11%).	Presorting required. Included partnership with Bulk Handling Systems (BHS) that would provide front end MRF equipment for plastics. MSW sorting required prior to plastic presorting.	Current facility produces process wastewater that meets Texas requirements for municipal treatment systems. Stated water input is 12% of feedstock input and 11% output requires disposal.	Standalone.	Requires team approach for a design, build, own, operate and finance delivery.	Yes. US commercial facility in operation. NHE US operating experience is limited (3 years). Fuel types and end uses on Kauai may prove difficult. Technology is concentrated on single waste stream. Low diversion potential for anticipated high cost.
Pyro Genesis Canada Inc.	Gasification	4 - US facilities (1 TPD to 10 TPD). One (10 TPD) demonstration facility operated one year at Hulburt Air Force Base, FL and closed. Other facilities are small systems on Navy ships (1 TPD to 5 TPD. No full scale commercial land based facility.	Established	Targeted streams: Unsorted municipal solid waste. Limits: Metals removal preferable. Diversion potential: 70-80%	10 to 100 TPD, has not been demonstrated	Skid mounted prosses equipment occur under roof. Typically 1 TPD requires 30,000 square feet and 100 TPD requires 116,000 square feet of area. Requires electricity from local grid. 10 TPD requires 2MVA substation. Requires standard water and sewer hook-ups for water feed and wastewater.	Range of feedstock to energy ratios provided. 10 TPD/340 kW (low) to 100 TPD/1680 kW (high).	Presort requirements include extensive shredding to 2-3 inch particle size.	Inert slag, wastewater and wastewater sludge, solid sorbent material, and spent activated carbon. Inert slag can be used in cement production.	Standalone, however power start-up required from local grid.	Capable of self design, build, own, operate and finance delivery approach.	Yes. No scalable land based commercial facility in operation. Demonstration facility and Navy ship units require extensive scalability.
Resynergi Inc.	Pyrolysis	1 - No fully commercial plant. US pilot plant 1 tpd clean plastics of specific types. Partner addresses traditional recyclables.	Undeveloped	Targeted streams: Plastics Limits: Waste stream limited to plastics (i.e., HDPE, LDPE, PP). Diversion potential: 10-15%	1 - 5 TPD (modular) Resynergi offers modular systems with a 1 TPD capacity. Claim multiple 5 tpd systems can be used to increase tonnage.	Minimum site size not provided. Electrical and water utility hook-ups required.	Liquid hydrocarbon.	Plastics must be presorted.	Does not address residuals.	Can be implemented on a standalone basis.		System was developed from research done at the University of Minnesota. No fully commercial facility. Only addresses traditional single stream recyclables.
STI Engineering Inc.	Autoclave/Steam Classification	No current commercial full scale landfill operations. Pilot testing developed and employed at one landfill.	Emerging	Targeted Streams: No waste stream processing required. Limits: No direct waste diversion form landfill. Requires 15,000 GPD of leachate for a 3-acre system Diversion: Indirect diversion of waste through reduction of waste mass in landfill (50%) due to accelerated decomposition of organic waste in the landfill.	275 TPD Estimated that a 3-acre rotational injection system could convert 275 TPD of insitu organics into landfill gas, producing 8.5 MW of electricity. .	Rotational well and piping system can be installed within ½ to 3 acres. Injection wells installed in waste mass and piping aboveground. No discussion of area required outside of landfill footprint for LFG gas to energy system.	Increased LFG production, electricity, and dry ice and other products from CO_2 component.	Stated the need for continued recycling to minimize inorganics in the landfill. Presorting or separation is not part of the proposed technology.	LFG condensate from increased landfill gas production. CO_2 could be removed from LFG and converted to dry ice, liquified CO_2 and other CO_2 end products.	LFG to energy equipment including treatment and combustion engine generators. Steam generating equipment.	Requires team approach for a design, build, own, operate and finance delivery.	No. No commercial system in operation. Would require permitting with unique provisions that may be difficult to obtain. Technology does not address immediate diversion of waste from landfilling. Long term indirect approach.
Sweer Gazoil Inc.	Pyrolysis	1 - No fully commercial facility. Demonstration plant in Canada	Undeveloped	Targeted streams: Plastics and used oils Limits: Technology requires plastics including: non-recyclable plastics and plastic film, plastic containers numbered 3-7, and plastic bags. Diversion potential: 10-15%	2000 TPY Capacity of Canadian facility, they claim is soon going to be expanded to 5000 TPY.	Minimum site size not provided besides the 5000 square feet facility footprint.	Produces diesel fuel, unspecified gases, and off-spec naphtha.	Exclude plastics and other inorganpresorting for plastics separate plastics from MSW. Only addresses plastics.	Coke and solid contaminants.	Facility can be implemented on a standalone basis with presorting system (by others).	Facility should be covered. Would be beneficial to have MSW sorting technology near this facility	Key staff have over 25 years of experience.
Taylor Biomass Energy	Gasification	1 - No commercial facility. US project in construction for extended period.	Undeveloped	Targeted streams: Pre-sorted MSW Limits: Pre-sorting required of MSW to remove recyclables and residual waste. Diversion potential: 80%.	500 TPD of MSW & 450TPD of C&D Capacity of NY facility and gasification facility is under construction to expand facility.	6 to 10 acres Requires industrial zoning and infrastructure to support 69 KV utility hook-ups.	Electrical power and PBF.	Front end MRF that sorts waste is sorted into 4 categories: unidentifiable waste, organic/biomass waste, inorganics, and household hazardous waste. All other waste is landfilled.	Residuals include ash from the gasifier, wood that is treated and sold as mulch, and minimal emissions.	A landfill for other wastes.	Facility is fully enclosed and requires temps of 1,500F.	Limited team experience. No commercial facility. Requires source separated plastics or presort facility (by others or not fully integrated to date).

WastAway	Refuse Derived Fuel Production	1 - US demonstration facility - not fully commercial and 1 - commercial facility not operating in Aruba. Production of RDF fuel only.	Emerging	Targeted streams: Pre-processing completed for municipal solid waste to remove metals, glass, and rocks from raw garbage. Organics are included in feed stock. Diversion potential: 80%.	140,000 TPY Project example sizes ranges from 50 to 150 TPD. WastAway offers two plant size options including 70,000 TPY to 140,000 TPY. They suggested a 140,000 TPY facility for Kauai. Does not include product user facility.	3 acres or more Requires truck access, connection to the KIUC grid, and 40 gallons of water per ton of waste.	Produces high-BTU fuel pellets. For example, a 140 TPY facility has the potential to produce pellets (120 KWh/ton), and fuel (1 mm BTU/ton) used by others.	Front end MRF included to produce RDF.	Does not address residuals or unmanaged wastes	Does not need another sorting technologies since WastAway has an automated sorting process. Use of RDF produced by others.	RDF production facility would require 23 to 25 employees.	No commercial facility currently in operation. Products produced are used by others not included in proposal.

Study of Feasible Technologies for Long-Term Management of Municipal Solid Waste on the Island of Kauai

Table C - Summary of Vendor Technologies

Thermal Technologies

Technology Vendor Name	Technology Description	Operating Experience (No. Operational Projects/Facilities & Location)	Established, Emerging or Undeveloped	Waste Streams Processed, Diversion Potential & Limitations	Processing Throughput (TPH, TPD, TPY)	Site Requirements (Minimum Acres, Utilities, Other etc.)	Products, Electricity, Fuel, Other Commodities Produced	Presort or Waste Separation Requirements for Technology	Residuals Wastes Not Managed, Wastewater or Other Byproducts	Other Required Non-Presort Type Support Facilities	Operating, Design Build, Financial, Other	Opinion of Commercial Viability (Yes/No), Risk and Other Evaluation Discussion
Covanta Energy, LLC	Direct Combustion	42 operating facilities. 37 - US, 2 - CAN, 1 - IE, 1 - UK, and 1 - IT.	Established	Targeted streams: MSW and dewatered sewage sludge. Diversion potential: 80%.	160,000 - 1,250,000 TPY US operated facility sizes ranged from 161,684 TPY (low Islip, NY) to 1,258,087 TPY (high Delaware Valley, PA).	4 to 6 acres Appropriate zoning with access to major roadways. Water, wastewater, electrical interconnect to KIUC grid, data/fiber.	Electricity. Smallest US facility (Islip, NY) produces 12.0 MW.	No presorting requirements other than removal of bulky wastes and non-processible wastes.	Bottom ash and residue would require landfilling (approx. 30% by volume of MSW H-POWER example)	Technology can be implemented on a standalone basis.	Capable of self design, build, own, operate and finance delivery approach.	Kauai project would be a small WTE facility, similar to their Islip, NY project.
Eco Waste (EWS, ECO Solutions)	Direct Combustion	4 - US small demonstration facility (10 tpd) that operated 1 year and is no longer operational. No full scale commercial land based facility. No commercial facilities in operation at this time.	Emerging	Targeted streams: MSW Diversion potential 80%	50 TPD - 100 TPD. Company provides two different sized plants but has 412 TPD facility in MA.	Minimum site size not provided Would require interconnect to KIUC grid.	Electricity and steam. Example project in the United States (MA) handled 412 TPD and produced 9.4 gross MW.	No presorting requirements other than removal of bulky wastes and non-processible wastes.	Claim that residual ash will go through an ash removal system that can recover 75% of metals that can be recycled. Only 4-5% of ash cannot be reused or recycled and would require landfilling.	Modular system can be implemented on a standalone basis.	Eco Waste system requires minimal construction since modules come prefabricated and are shipped to site. Tipping floor requires a negative pressure to control dust and odor. Natural gas, propane, or fuel oil are required for start-up to get to an appropriate temperature.	Modules can be taken offline if, for example, improved diversion efforts result in reduced waste volumes.
The Babcock & Wilcox	Direct Combustion	25 - US and 300+ Globally	Established	Targeted streams: MSW Limits: Pre-processing of municipal solid waste is optional. Can be used as is or treated to remove certain components. Diversion potential: 80%.	17 TPH	8 to 10 acres. The site must be in accordance with local zoning requirements with utility hook-ups for water, gas/ oil, electricity.	Electrical power and direct heating. Example project in Borden, Sweden generates 8 MW and handles 17.3 TPH.	RDF facility has presort requirements, mass burn does not besides removing bulky or non-processable waste.	Residual wastes include ash, unburned carbon, and spent reagent from acid gas removal process.	System can be implemented on stand alone basis.		Scalability depends on client needs. Babcock and Wilcox prefer to not operate facilities.
Urbaser	Mechanical Biological Treatment, Direct Combustion, Anaerobic Digestion, Mixed Waste Processing	Operations in 30 different countries. No operating systems in the US (only organics).	Established	Targeted streams: Pre-processing requirements for municipal solid waste described provided as required for system. Diversion potential: 80%.	600,000 TPY From project example from Lisbon handles in a waste-to-energy/ integrated waste treatment facility. Project listed as both organics and MSW processing types.	15 acre site Typical utility hook-ups	Commodities produced depends on the technology selected. For example, the Lisbon Integrated Solid Waste facility produces 50.6 MWe. System may produce natural gas.	Material separation included in integrated solid waste facility which includes trommel screens, ballistic separator, optical separator, and magnetic separator.	Mentions "reject waste".	Depending on Kauai needs, a system can be tailored. They suggest having WTE facility in support of a larger integrated waste system.	Urbaser has a "Zero Reject" philosophy.	Integrated system can be scaled depending on needs of Kauai.

Study of Feasible Technologies for Long-Term Management of Municipal Solid Waste on the Island of Kauai

Table C - Summary of Vendor Technologies

Mechanical Technologies

Technology Vendor Name	Technology Description	Operating Experience (No. Operational Projects/Facilities & Location)	Established, Emerging or Undeveloped	Waste Streams Processed, Diversion Potential & Limitations	Processing Throughput (TPH, TPD, TPY)	Site Requirements (Minimum Acres, Utilities, Other etc.)	Products, Electricity, Fuel, Other Commodities Produced	Presort or Waste Separation Requirements for Technology	Residuals Wastes Not Managed, Wastewater or Other Byproducts	Other Required Non-Presort Type Support Facilities	Operating, Design Build, Financial, Other	Opinion of Commercial Viability (Yes/No), Risk and Other Evaluation Discussion
Bulk Handling Systems	Mixed Waste Processing	3 - US.	Established	Targeted streams: Mixed Waste, single stream plastics, construction and demolition, and organics. Diversion potential: 25-50%	15-100 TPH From example projects in the US MSW Recovery Systems	5 acres, 4000 amps electrical service, and water for sprinkler system.	Compost, recyclables, organics, and fuel feedstock.	N/A	Not included.	Water service, possible sewer, electrical hook-up, and stormwater pond.	Composting typically achieves a 25-50% reduction in mass, depending primarily on incoming feedstock composition, retention time and process design.	Not included. May require source separated organics to achieve objectives. Needs organics and/or RDF facility included for diversion.
CP Group	Mixed Waste Processing	450 - U.S and Globally currently operating. 500 over the company's history.	Established	Targeted streams: municipal solid waste, single stream material, construction and demolition waste, E-waste, green waste, PET, HDPE, #3-#7 plastics, 2D paper, films, and residue	40 TPH From example project in Layton, Utah processes municipal solid waste.	30,000 to 100,000 square feet.	RDF and recyclable products.	System is built to sort through waste. The system include 4 pre-sort chutes: one for cardboard products, one for plastics, one for scrap metals, and one for non-processible waste and residue.	Residues will be transferred to a landfill.	Other support facilities include a RDF consumption facility, an organics handling facility, and a landfill.	Claims there is a reduction in landfilling and shipping costs but does not estimate how much.	The company has experience and operate many facilities nationally and internationally.
General Kinematics Corporation	Mixed Waste Processing	Operating experience in the US as an equipment supplier but not all equipment required for a complete facility and no operating experience.	Undeveloped	Targeted streams: Municipal solid waste and construction and demolition waste. Diversion potential: 10% - 20%.	Example facility: Covanta Pinellas-101,388 truckloads of MSW processed in 2020. (provided ash conveyor systems, not the WTE plant).	Minimum site size not provided	Recyclables and metals.	Many presort requirements, see proposal.	Residuals not specified.	Technology can be implemented on a standalone basis.		Did not include scale up or scale down options. Equipment supplier but does not provide complete facilities.
MachineX	Mixed Waste Processing	Numerous systems in North America	Established	Targeted streams: Municipal solid waste, mixed dry recyclables, mixed construction and demolition waste, and organics. Diversion potential: 10% - 25% recyclables up to 80% with RDF recovery	15 TPH From example facility at Public Power Solutions in the UK.	Minimum site size not provided Basic electrical and water hook-ups.	Recyclables and RDF	No presort requirements other than removal of bulky waste.	Not included.	RDF consumption facility and landfill.		Need RDF facility (by others) to use products.

Common Acronyms	Definitions
AD	Anaerobic Digestion
GPD	Gallons Per Day
GPY	Gallons Per Year
HDPE	High-Density Polyethylene
KIUC	Kauai Island Utility Cooperative
MYT	Maximum Yield Technology
MRF	Materials Recovery Facility
PET	Polyethylene
PTD	Plastics to Diesel
RDF	Refuse Derived Fuel
RNG	Renewable Natural Gas
TPH	Tons Per Hour
WTE	Waste to Energy

Appendix D

Summary of Screened Technologies

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Study of Feasible Technologies for Long-Term Management of Municipal Solid Waste on the Island of Kauai

Table D - Summary of Screened Technologies

	Tier 2 Screening: Performance Criteria					
Technology Type	**Criterion #1 Commercial Readiness**	**Criterion #2 Applicability to County's Waste Stream Characterization**	**Criterion #3 Compliments Existing Waste Diversion**	**Criterion #4 Utilizes Process Output**	**Criterion #5 Standalone or Combined Technologies**	**Tier 1 and 2 Screening Results**
Direct Combustion	Feasible Established technology in the U.S. for management of MSW.	Conditionally Feasible Can process most non-diverted MSW without front-end mechanical processing. Current quantity of landfilled MSW may not support a minimum sized facility.	Feasible Can process most MSW or residuals/recyclables from other diversion programs.	Conditionally Feasible Electricity is typically produced, which would require PPA with KIUC or other approved energy user. Project economics can be challenging if offered price for electricity is low.	Feasible Can be operated as a standalone technology.	**Established - Feasible**
Front-End Mechanical Processing - Single-Stream and Mixed Waste Processing	Feasible Established front-end technologies in the U.S. for management of waste.	Conditionally Feasible Single-stream MRF would require implementation of a curbside collection program. Current landfilled MSW can be processed through a mixed waste MRF.	Feasible Front-end sorting of recyclable materials and/or landfilled MSW used with other diversion technologies.	Feasible Front-end sorting of recyclable materials and/or landfilled MSW used with other diversion technologies.	Feasible Front-end sorting technologies combined with other diversion technologies. Not considered a standalone technology for final management of waste.	**Established - Feasible**
Front-End Mechanical Processing - Refuse Derived Fuel and Solid Recovered Fuel	Feasible Established front-end technologies in the U.S. for management of waste.	Feasible Front-end processing of landfilled MSW can be used with other diversion technologies.	Feasible Front-end processing of landfilled MSW can be used with other diversion technologies.	Feasible Front-end processing of landfilled MSW can be used with other diversion technologies, or with boiler, kiln or similar type fuel users.	Feasible Front-end processing technologies combined with other diversion technologies. Not considered a standalone technology for final management of waste.	**Established - Feasible**
Anaerobic Digestion (AD)	Feasible Established technology in the U.S. for management of organic waste.	Conditionally Feasible Kauai is in need of a more immediate large-scale solution to waste diversion. Technology requires front-end mechanical processing or curbside collection of organics. Could be applicable in a combined system.	Contionally Feasible Kauai's curbside collection program does not capture organics as a recyclable. Residential and commercial collection of green waste is currently composted.	Conditionally Feasible Produces methane/biogas that can be cleaned and utilized similar to natural gas. Can also be combusted in an engine with minimal cleaning. Kauai does not have a natural gas utility.	Conditionally Feasible Increased organic diversion would need to be implemented to function as a standalone technology. Technology would need to be combined with front-end mechanical processing or a curbside collection program. Can be used in combination with most other technologies.	**Established - Conditionally Feasible**

Study of Feasible Technologies for Long-Term Management of Municipal Solid Waste on the Island of Kauai

Table D - Summary of Screened Technologies

	Tier 2 Screening: Performance Criteria					
Technology Type	**Criterion #1 Commercial Readiness**	**Criterion #2 Applicability to County's Waste Stream Characterization**	**Criterion #3 Compliments Existing Waste Diversion**	**Criterion #4 Utilizes Process Output**	**Criterion #5 Standalone or Combined Technologies**	**Tier 1 and 2 Screening Results**
Gasification	Feasible Emerging technology with at least one known commercial-scale facility operating in the U.S. and others operational outside the U.S. (Canada and Japan). There are smaller dual-chamber "gasification" facilities operating in the U.S.	Feasible Various waste types are able to be processed. Requires varying levels of front-end mechanical processing to generate an acceptable feedstock.	Feasible Technology can compliment existing diversion programs. Front-end processing would remove additional recyclables and divert waste from landfilling.	Conditionally Feasible The technology can produce electricity or a fuel product. Fuels typically require further refinement and a market would need to be identified on Kauai. Some technologies can produce a vitrified aggregate (slag) that can be resused in the construction industry (further increasing diversion).	Conditionally Feasible Requires front-end processing and most likely a treatment technology to produce a marketable fuel.	**Emerging - Feasible**
Pyrolysis	Conditionally Feasible Emerging technology with only a few commercial facilities in operation globally. U.S. facilities reported to be under development. Facility in Texas operating for 3 years using non-recycled plastic as feedstock.	Conditionally Feasible Some technologies reported to be able to process a wide range of waste types depending on the level of front-end processing. Other technologies target specific waste streams (e.g., all or selected types of plastics).	Conditionally Feasible Some technologies could compliment existing diversion programs depending on feedstock type (e.g., use of recyclable and non-recyclable plastics).	Conditionally Feasible This technology typically produces different types of fuels, gases, and pertroleum distillates that may or may not be marketable on Kauai.	Conditionally Feasible Requires front-end processing to separate plastics and other specific waste types from the MSW. Would most likely require treatment of process outputs to be marketable on Kauai.	**Emerging - Conditionally Feasible**
Mechanical Biological Treatment	Conditionally Feasible Emerging technology with a few commercial facilities operating in the U.S. and Europe.	Conditionally Feasible Technology can process MSW with minimal front-end processing and at relatively high throughputs	Conditionally Feasible Technology could compliment existing diversion programs through seperation of recyclables and utlization of other waste types as a fuel product.	Conditionally Feasible Recovery of recyclables and production of gas/fuel products. Anaerobic digestation or composting process produces a biogas that can be used to dry the processed waste into a usable fuel product. The produced fuel can be used in another thermal application (e.g., boiler, kiln or other diversion technology).	Conditionally Feasible Combined with a thermal technology as user of the fuel product.	**Emerging - Conditionally Feasible**

Study of Feasible Technologies for Long-Term Management of Municipal Solid Waste on the Island of Kauai

Table D - Summary of Screened Technologies

	Tier 2 Screening: Performance Criteria					
Technology Type	**Criterion #1 Commercial Readiness**	**Criterion #2 Applicability to County's Waste Stream Characterization**	**Criterion #3 Compliments Existing Waste Diversion**	**Criterion #4 Utilizes Process Output**	**Criterion #5 Standalone or Combined Technologies**	**Tier 1 and 2 Screening Results**
Plasma Arc Gasification	Non-feasible No established commercial scale facility is operational in the U.S. Several significant project failures have occured at commercial-scale facilities in other countries.	Not evaluated (non-feasible technology)	Not evaluated (non-feasible technology)	Not evaluated (non-feasible technology)	Not evaluated (non-feasible technology)	**Undeveloped - Non-Feasible**
Autoclave/Steam Classification	Conditionally Feasible No established commercial scale facility is operational in the U.S.. Responding technology utilized steam injection demonstartion study.	Non-Feasible Increasing the biodegradation rate of waste by injecting steam into the landfill appears to be a plausible long-term approach in renewing disposal capacity. The technology does not provide a diversion approach applicable to Kauai's waste stream.	Not evaluated (non-feasible technology)	Not evaluated (non-feasible technology)	Not evaluated (non-feasible technology)	**Undeveloped - Non-Feasible**