FOOD WASTE DIVERSION AND UTILIZATION IN HUMBOLDT COUNTY

By

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ABSTRACT

FOOD WASTE DIVERSION AND UTILIZATION

IN HUMBOLDT COUNTY

Juliette P. Bohn

This thesis investigates the feasibility of establishing a regional food waste digester facility in Humboldt County. California state law AB 939 mandates that all jurisdictions divert 50% of their waste stream away from the landfills. Although successful recycling and green waste composting programs have been developed in the County, some cities have yet to reach the diversion target. The largest component of the remaining disposed waste stream is food waste (~20%). For the purpose of establishing a food waste diversion program, the economics and environmental impacts of a food waste digester was compared to in-vessel composting as an alternative to hauling waste to the landfill (380 miles).

The results of the analysis indicate that establishing either alternative will reduce the overall cost of waste management by $12 to $16 million over a 20 year time horizon. The anaerobic digestion alternative has the lowest life cycle cost, due in large part to the renewable energy generation potential of anaerobic digester systems. Over time, as energy prices rise, composting and long-distance waste hauling strategies will become more expensive while the economics of anaerobic digestion systems improve.

A regional food waste digestion facility will reduce greenhouse gas emissions in three ways: first, from avoided long-distance waste hauling (326 $MTCO_2e$/year); second, from offset grid electricity use (540 $MTCO_2e$/year); and third, from avoided methane emissions at landfills (average 5,000 $MTCO_2e$/year). These reductions will help participating jurisdictions to meet future requirements for carbon emissions accounting. Establishing a food waste digester facility will contribute to the long-term sustainability of the region.

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I dedicate this work to my parents who gave up everything to bring me into this world.

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LIST OF ACRONYMS

AD – Anaerobic Digestion
ADA – Americans with Disabilities Act
BTU – British Thermal Units – a measure of heat produced from combustion
C:N – carbon to nitrogen ratio
CAR – Climate Action Reserve
CCR – California Code of Regulations
CCX – Chicago Climate Exchange
CEQA – California Environmental Quality Act
CH_4 - Methane
CIWMB - California Integrated Waste Management Board
CO_2- Carbon dioxide
CPI – Consumer Price Index
CPUC – California Public Utility Commission
DFG – Department of Fish and Game
EBMUD – East Bay Municipal Utility District
EIA – Energy Information Administration
EIR – Environmental impact report
FOG – Fats, Oils, and Grease
GHG – Greenhouse Gas
H_2S – Hydrogen sulfide
HSU – Humboldt State University
HWMA – Humboldt Waste Management Authority
IEUA – Inland Empire Utilities District
IPCC – Intergovernmental Panel on Climate Change
KW – Kilowatt
kWh- Kilowatt hour
LCC – Lifecycle cost
LEA – Local enforcement agency
MC – Moisture content
MPR – Market price referent
MJ – Mega joule
MSW – Municipal solid waste
$MTCO_2$ – Metric tons carbon dioxide
$MTCO_2e$ – Metric tons carbon dioxide equivalent
MTCE – Metric tons carbon equivalent
MW-Megawatt
MWh – Megawatt hour
N_2O – Nitrous oxide
NCUAQMD – North Coast Unified Air Quality Management District
NCRWQCB – North Coast Regional Water Quality Control Board

NH_3 – Ammonia
NPV – Net present value
O&M – Operation and maintenance
OLR – Organic loading rate
PG&E – Pacific Gas and Electric
PV – Present value
RFI – Request for information
RPS- Renewable portfolio standard
SCAQMD – South Coast Air Quality Management District
SLR – Solids loading rate
SMUD – Sacramento Municipal Utility District
SOI – Solicitation of interest
SRRE – Source Reduction and Recycling Element
SSO – Source separated organics
SWAP – Sheriff's Work Alternative Program
TS – Total solids
UPV – Uniform present value
USACE – US Army Corps of Engineers
USCC – US Composting Council
US EPA - United States Environmental Protection Agency
VOC – Volatile organic compounds
VS – Volatile solids
WWTP – Waste Water Treatment Plant

CHAPTER 1. INTRODUCTION

The establishment of affordable, effective waste management is the key to a community's long term sustainability. Effective waste management practices improve public health and safety, prevent soil and water contamination, conserve natural resources, and reduce greenhouse gas emissions. This thesis focuses on food waste management by investigating the feasibility of establishing a regional food waste diversion program for Humboldt County.

The purpose of developing this program is to divert food waste away from landfills in order to reduce the cost and environmental impacts of solid waste management. The proposed program will utilize the anaerobic digestion process to convert food waste to renewable energy and soil amendments. This program is regional in scope in order to address the diseconomies of scale faced by rural communities in Humboldt County who have fewer resources with which to address environmental problems.

Benefits derived from this project are three-fold. First, local jurisdictions can reduce commercial sector solid waste disposal by up to 34%[1] by diverting food waste from landfills. Reducing the amount of food waste sent to landfills will help these jurisdictions reach and maintain compliance with California waste diversion mandates.[2]

[1] According to the California Department of Resources Recycling and Recovery (CalRecycle), waste stream profile for Humboldt County, this figure could be as high as 34%.
[2] AB 939 The California Integrated Waste Management Act mandates that all jurisdictions divert 50% of their waste away from landfills by the year 2000.

Second, anaerobic digestion of food waste will create clean, renewable energy in the form of biogas which can be used to produce heat, electricity or vehicle fuel. Finally, this project will reduce the carbon footprint of Humboldt County's waste management system. This can be achieved by avoiding uncontrolled emissions of methane[3] at landfills. Through processing this waste stream locally, carbon emissions associated with trucking solid waste to landfills in Medford, Oregon and Anderson, California are also avoided. These benefits are quantified in the sections that follow, and can be seen in Table 1.1.

This document frames the opportunity for food waste diversion through anaerobic digestion by first describing the background of waste diversion policy as well as the quantity of food waste disposed in landfills. The next section describes the impacts of putting food waste in landfills and examines the traditional food waste diversion options. Anaerobic digestion is presented as an alternative food waste diversion option. Case studies of the existing food waste digestion infrastructure are included to provide a basic understanding of the current use this technology in North America.

The subsequent section details the proposed digester system including the main pre-processing and processing equipment that will be used to convert food waste to energy. The chapter that follows this section includes the methodologies used for the economic and greenhouse gas reduction analyses. The final chapters contain a narrative describing the results of the analyses, the main conclusions and recommendations, and the limitations of this study.

[3] Methane is a powerful greenhouse gas that is formed when food waste and other wastes are disposed in landfills.

Table 1.1 Key results from the feasibility study analysis. The values shown are the results from the 10,000 ton / year commercial-sector food waste diversion scenario.

Table of Key Results		
Metric	**Value**	**Unit**
Tons of organic waste diverted / year from commercial sector[4]	10,000	Tons / year
Estimated capital cost	$7.8M	Million $
Estimated operation and maintenance costs	$340,000	$ / year
Life cycle cost reduction of establishing an organics diversion program vs. current waste management strategy	$12 to $16M	Million $[5]
Tipping fee of regional organic waste processing vs. current tipping fee	$95 vs. $129	$ / ton
Renewable energy production	45,000,000	ft^3 biogas / year
Gross renewable electricity production	2,500	MWh / year
Net renewable energy production (25% parasitic load)	1,900	MWh / year
Offset grid electricity at the Eureka waste water treatment plant	1,100	MWh / year
Demand charge reduction at Eureka waste water treatment plant[6]	$25,000	$ / year
Renewable electricity sold to PG&E	817	MWh / year
Revenues from renewable energy sold to PG&E[7]	$93,000	$ / year
Offset long-haul truck trips[8]	369	# trucks / year
Savings from avoided long-distance waste hauling	$260,000	$ / year
Carbon emissions reductions from offset long-distance hauling	326	$MTCO_2e$ / year
Carbon emissions reductions from offset grid electricity use	540	$MTCO_2e$ / year
Average carbon emissions reductions from avoided landfilling	5,000	$MTCO_2e$ / year

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[4] Commercial sector waste streams considered in this analysis include food waste, grease trap waste and cheese whey.
[5] The time horizon for this analysis is 20 years.
[6] Demand charges are a component of PG&E's E-19 Large Commercial electricity rate schedule. Demand charges are charges, in addition to a facility's electricity usage, that are based on the highest demand (kW) periods during the day. By generating electricity onsite, the magnitude of the grid demand peaks are reduced, reducing the demand charges.
[7] The revenues from electricity sales are based on the current Feed-in Tariff rates offered by Pacific Gas & Electric.
[8] Offset long-haul trucking refers to the food waste portion of the total organic waste tonnage only.

CHAPTER 2. BACKGROUND

The Integrated Waste Management Act of 1989 (CA AB 939) established the California Integrated Waste Management Board (CIWMB). As of January 2010, this agency's name has been changed to the Department of Resources, Recycling and Recovery (CalRecycle),[9] and is now a department within the California Natural Resources Agency. The CIWMB (now CalRecycle) was formed to "oversee, manage, and track California's 92 million tons of waste generated each year," including enforcing AB 939. AB 939 was created in order to address the perceived landfill capacity crisis facing the highly populated cities in California. This state law mandates that California cities and counties each divert 50% of their waste stream away from the landfill by the year 2000. Jurisdictions that have not reached this waste reduction goal must show that they are actively implementing programs that will eventually bring them into compliance. Fines for non-compliance can be quite substantial, up to $10,000 per day.[10] As a result, most jurisdictions have either reached the 50% waste diversion level or have received extensions due to sustained efforts to achieve this goal.

The Humboldt Waste Management Authority (HWMA) is a Joint Powers Authority that is responsible for managing and tracking over 100,000 tons of waste that is generated annually in Humboldt County. HWMA is also responsible for assisting its member jurisdictions in achieving AB 939 compliance. Efforts to comply with AB 939

[9] The names CalRecycle and DRRR refer to the same agency. The citations for some of the reference materials from CalRecycle are still written as "CIWMB" as that was the name of the agency when the reports were written.
[10] See http://www.calrecycle.ca.gov/ for more information on non-compliance fines.

have led to the development of successful recycling, hazardous waste, and composting programs in the County; however, four cities in Humboldt County have yet to reach the 50% diversion target.[11]

Food waste represents a significant portion of the remaining waste stream. According to the California Department of Resources, Recycling and Recovery waste stream profiles for Humboldt County, food waste comprises 20% of the residential waste and 34% of the business waste disposed.[12] Other waste characterization studies cite lower numbers (e.g., 18.8% from the Humboldt County's 1990 County-wide waste characterization study) indicating that the true value is likely to be somewhere within these bounds. For this reason, HWMA and the member cities are now looking at food waste to expand diversion.

Another important driving factor for food waste diversion is the cost of waste disposal in Humboldt County. Solid waste is hauled an average of 187 miles out of county to the Dry Creek landfill in White City, OR and to Anderson landfill just outside of Redding, CA. A significant portion of the cost of waste disposal is tied to the fuel costs. Therefore, when the cost of diesel fuel increases, the cost of waste disposal also rises. Processing food waste locally will help to minimize the County's vulnerability to fuel price fluctuations and increases over time. A map showing the hauling routes can be seen in Figure 2.1.

[11] The source for this information is the HWMA records of waste diversion for the year 2008. The cities that have not yet reached the diversion mandate are Eureka, Fortuna, Ferndale, and Rio Dell.
[12] Waste stream profiles for all jurisdictions in the state of California can be found at: http://www.calrecycle.ca.gov/Profiles/ .

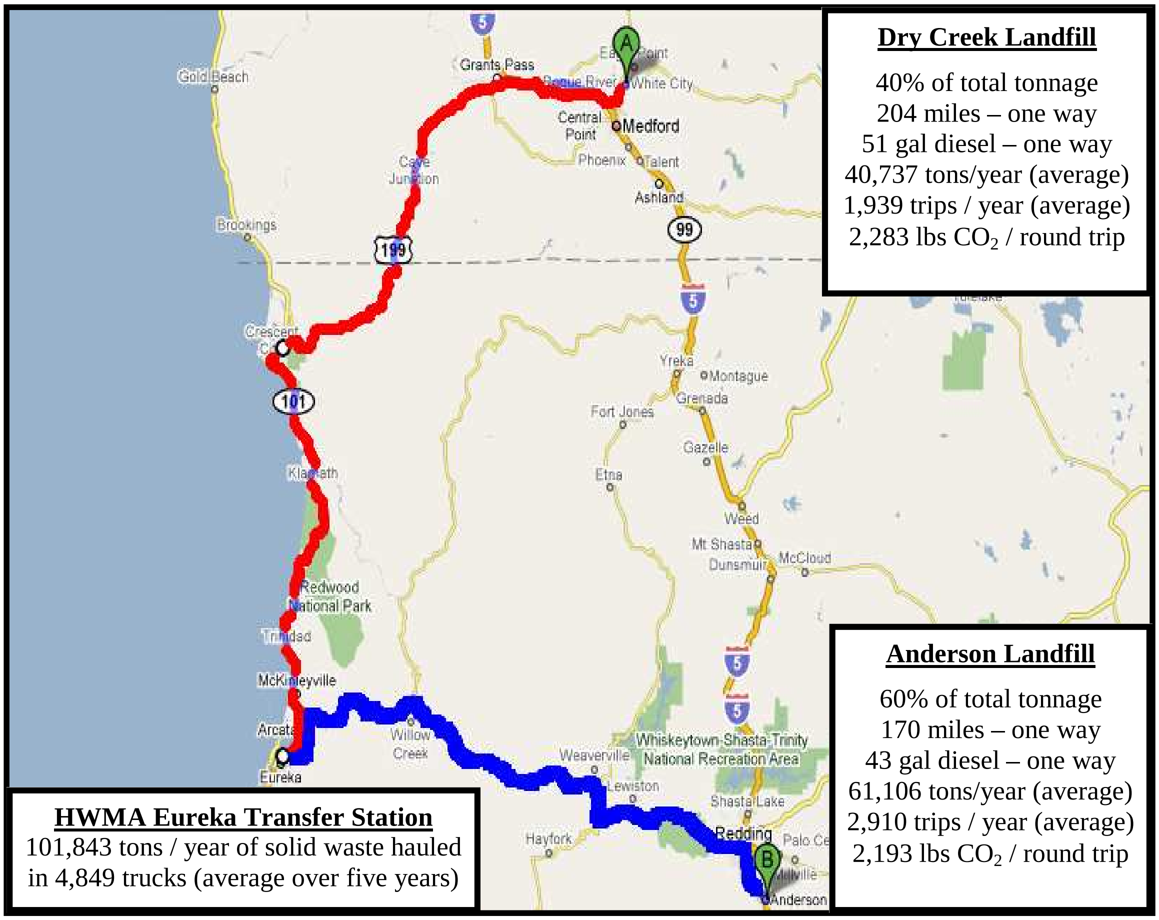

Figure 2.1 This map shows Humboldt County's solid waste disposal routes. Map source: Google Maps.

Over the five years spanning 2004 through 2008, Humboldt County has hauled an average 100,000 tons of waste per year to out-of-county landfills. In 2009, disposed waste decreased by ~20% due to the global economic downturn. Solid waste disposal quantities are likely to return to historic levels once the economy recovers, and as the local population grows over time. Therefore, there is a need to establish a new diversion program in order to reduce long distance hauling to out-of-county landfills and to mitigate the economic and environmental costs associated with this waste management strategy.

This feasibility study explores three food waste management options: 1. business as usual , i.e., continue disposing food waste as garbage that is trucked to landfills, 2. municipal-scale composting, and 3. development of a stand-alone food waste digester. Analyses central to the study include the estimate of the recoverable food waste in the region, the pre-processing and processing equipment required to process this waste, and the total life cycle cost of establishing a food waste digestion facility compared to other options. The life cycle cost analysis includes potential renewable energy production, annual operating and amortization costs, and prospective reductions in waste management costs. Finally, this study includes estimates of the greenhouse gas emissions reductions that can be achieved through food waste diversion. The results of these analyses provide useful information for planning and implementing a food waste diversion program in Humboldt County.

Food Waste Disposed in Landfills

Each year Americans discard of 25% of all food produced annually, with less than 3% of this waste diverted from the waste stream (US EPA, 2009a).[13] Food waste is the

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[13] Food discards begin on the farm where food is damaged by extreme weather, pest infestations or is lost due to consumer demand for blemish-free produce. Food loss continues as it enters the marketing system. Marketing system losses occur in storage due to mold or deterioration, damage in transportation and handling. Finally, food discards occur in food preparation and uneaten food from plates in restaurants and homes. For more information see: http://www.ers.usda.gov/Publications/FoodReview/Jan1997/Jan97a.pdf.

single largest specific material[14] in the California waste stream as well as the heaviest and wettest portion of the waste stream (Figure 2.2).

Food waste is classified into two categories: pre-consumer and post-consumer. Pre-consumer food waste consists of leftovers from food preparation, excess food scraps from kitchens, and any other food waste that has not been served to consumers. Post-consumer food waste consists of the leftovers on plates and food that is no longer fit for consumption (i.e., spoiled). Food waste decomposes quickly, and can attract pests such as rats and flies as well as cause unpleasant odors; this is the reason trash is collected on a weekly basis.[15]

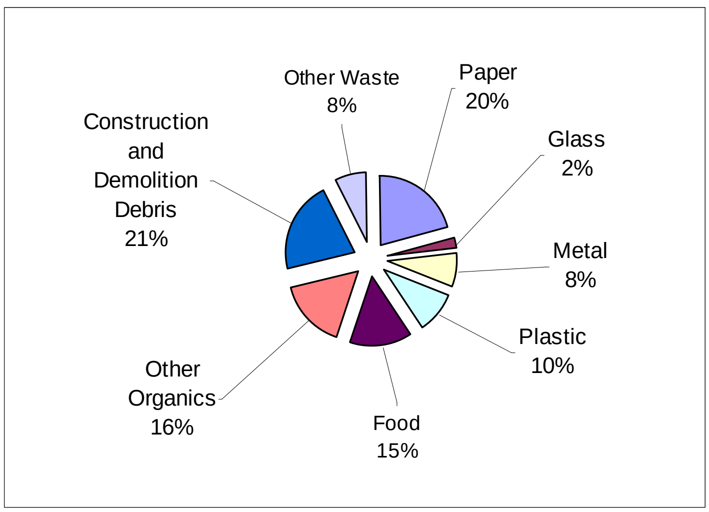

Figure 2.2 Components of the California disposed waste stream 2003

[14] "Specific material" refers to the individual materials in a given category. For example, food waste is part of the organics category as is lumber in the construction and demolition debris category. Paper includes several different specific materials such as cardboard, office pack, and newspaper. For this report, food waste has been shown separately, whereas the other specific materials are not.

[15] Humboldt County Code: Title 5, Division 2 (Solid Waste), Section 521-4c. The code states that putrescible waste from commercial entities should be collected twice a week, and putrescible waste from residential entities should be collected at least once a week. The purpose of this code is to prevent the propagation of disease vectors, nuisances, and pests.

For this report, the quantity of local food waste available for diversion was estimated using the following sources:

- Source Reduction and Recycling Element (1992) County-wide waste characterization commissioned by Humboldt County

- California Department of Resources Recycling and Recovery (CalRecycle) waste stream profiles (2004). Available from CalRecycle website: http://www.calrecycle.ca.gov/Profiles/

- U.S. Environmental Protection Agency (US EPA) Municipal Solid Waste Generation, Recycling, and Disposal in the United States: Facts and Figures for 2007 (2008). Waste stream characterizations accessed via: www.epa.gov/osw

- Oregon Statewide Waste Composition (2005/06). Oregon Department of Environmental Quality. Available at: http://www.deq.state.or.us/lq/sw/disposal/2005study.htm
- 2008 Alameda County Waste Characterization Study. Waste characterizations performed by RW Beck for Alameda County Waste Management. Accessed via: (http://stopwaste.org/)

- Oregon Solid Waste Composition 2005/06 Marion County Supplement (2007). Oregon Department of Environmental Quality – this was an additional waste characterization funded by Marion County to obtain a more detailed waste characterization which could then be compared to the State-wide characterization. Available at: http://www.deq.state.or.us/lq/sw/disposal/2005study.htm

The percent of food waste in the waste stream reported by these studies can be seen in Table 2.1. Food waste is reported to make up 10.5% to 20.5% of the total disposed waste stream, and 14.9% to 26.1% of the commercial waste stream, with averages of 15.8% and 18%, respectively.

Table 2.1 Reference waste characterization studies

Source:	**Year**	**% Food Waste in Disposed Waste Stream**	**% Food Waste in Commercial Sector**	**Scale**
Humboldt County SRRE	1992	N/A	18.6%	County-wide
CalRecycle: Humboldt	1999	N/A	17.2%	County-wide
CalRecycle	2004	14.6%	18.8%	State wide
CalRecycle: Humboldt	2004	N/A	17.2%	County-wide
CalRecycle	2008	14.4%	15.2%	State-wide
US EPA	2007	18.2%	N/A	Nation-wide
Alameda County	1995	10.5%	14.9%	County-wide
Alameda County	2000	11.9%	16.2%	County-wide
Alameda County	2008	18.7%	26.1%	County-wide
Oregon Statewide	2005/2006	15.7%	N/A	State-wide
Marion County	1998	15.3%	N/A	County-wide
Marion County	2002	17.7%	N/A	County-wide
Marion County	2005	20.5%	N/A	County-wide
Average		15.8%	18.0%	

The focus of this feasibility study is the food waste disposed by the commercial sector. It is assumed that the project will have a higher level of initial impact if food waste is collected from the commercial sector first, as this would require the fewest pick-up locations for the local franchise haulers for a given quantity of food waste. Table 2.2 shows the estimated quantity of food waste available for diversion using the average values from the waste characterizations cited. Note that the Humboldt County waste characterization study and the CalRecycle estimates for Humboldt County both yield higher levels of food waste in the commercial sector than the average values.

Although the Humboldt County waste characterization is 20 years old, there has been little change in terms of food waste diversion in the County. The only notable forms of food waste diversion in the County are the collection of pre-consumer food waste by food banks and pig farms, the City of Arcata's subsidy on a limited number of home compost bins, and voluntary food scrap composting by some Arcata restaurants. Otherwise, the majority of County's food waste management strategy has remained unchanged (i.e., landfill disposal).[16] Therefore, the quantity of food waste in the disposed waste stream shown in Table 2.2 is considered to be conservative.

[16] The Humboldt County waste characterization was commissioned in order to identify the waste diversion strategies that could be implemented to reach the 50% diversion mandate (CA AB 939). The first changes made were to remove ash going to the landfills and apply it to local soils. This was followed by establishing traditional recycling (paper, plastic, glass, metals) and establishing a green waste composting facility. Food waste and construction and demolition debris are the next largest remaining portions of the disposed waste stream.

Table 2.2 Quantity of food waste available for diversion

Solid Waste (tons / Year)		Food Waste (tons / Year)		% Diversion Humboldt County[17]
Jurisdiction	Average (2003-2008)[18]	In Disposed Waste	In Commercial Waste[19]	Commercial Food Waste
Arcata	11,454	1,807	1,347	1.3%
Blue Lake	991	156	116	0.1%
Eureka	34,891	5,503	4,102	4.0%
Ferndale	1,117	176	131	0.1%
Fortuna	9,449	1,490	1,111	1.1%
Rio Dell	1,640	259	193	0.2%
Trinidad	502	79	59	0.1%
Unincorporated	41,799	6,593	4,914	4.8%
TOTAL	**101,843**	**16,064**	**11,973**	**11.8%**

Food waste Characteristics

Nationally, food waste is the largest single component of the waste stream by weight. This is due to the high moisture content (70-80%) of this waste. The majority of the food waste is landfilled where it decomposes under anaerobic (absence of oxygen) conditions creating methane and carbon dioxide – a mixture known as biogas. The EPA states that methane from landfills accounts for 34% of all national methane emissions (US EPA, 2006b). Reducing food waste in the landfills is therefore an important step towards reducing greenhouse gas emissions associated with waste management.

[17] The diversion percentages listed below are based on the overall waste stream for Humboldt County, i.e., they do not represent the diversion potential from each jurisdiction.
[18] Five year average waste disposal in Humboldt County was calculated using data from HWMA records.
[19] This calculation assumes 64% of Humboldt County's waste is commercial waste, the remainder being residential waste. This estimate comes from CIWMB waste stream profiles for Humboldt County which is based on 1999 state-wide estimates (http://www.ciwmb.ca.gov/Profiles/County/CoProfile1.asp).

Because of its high moisture content, decomposing food breaks down very quickly and leaches metals and other substances into solution, creating a toxic slurry known as leachate.[20] Leachate can contaminate nearby water sources, and requires monitoring and collection. Decomposing food waste in landfills also creates methane and volatile organic compounds. Methane (CH_4) is a combustible gas which is the primary constituent in natural gas (used in households for heating and cooking) and is explosive at 5% to 15% in air (Tchobanoglous, 2002). Volatile organic compounds are carbon-based substances that are easily vaporized under normal atmospheric pressures, and are often toxic and/or odorous. The combination of methane and volatile organic compound emissions presents an air quality risk as well as a safety hazard. Mitigating these air and water quality problems is an expensive, long term waste management issue associated with landfills.

Food waste has a high energy content which can be converted into methane under anaerobic conditions. The source of this methane is the microbial decomposition of the volatile solids in the food waste. Food waste and other organic wastes are comprised of a solids component (total solids) and water. The total solids content of the food waste (i.e., the solids that remain when all water has been removed) is made up of fixed solids and volatile solids. The fixed solids are not easily decomposed and will remain relatively unchanged throughout the anaerobic digestion process. The volatile solids component is

[20] Leachate is a liquid that is formed when water percolates through solid waste and extracts dissolved or suspended components from the decomposing waste. The quantity of leachate formed is directly related to the amount of water entering a landfill either from external sources (rainfall), and/or from the water content of the waste itself. Leachate formed from rainwater dissolves organic compounds into solution. Leachate formed from organic waste, such as food waste decomposing anaerobically in the landfill, forms an acidic solution which can dissolve inorganic compounds (heavy metals) into solution (Tchobanoglous, 2002).

the portion of the waste that is easily decomposable. A consortium of anaerobic microorganisms decomposes the volatile solids and converts them into biogas (methane and carbon dioxide). Food waste contains 20% to 30% total solids of which 85-90% are volatile solids. These characteristics as well as the density and energy content of the biogas derived from food waste can be seen in Table 2.3.

Table 2.3 Typical Food waste characteristics

Characteristic	Quantity	unit
Moisture content	70 - 80	%
Total solids (TS)	20 - 30	%
Volatile solids (VS) as % of TS	85 - 90	%
Density	2,000	lbs/yd^3
Density (metric)	1,187	kg/m^3
Average ft^3 biogas per wet ton (STP)	4,291	ft^3/ton
Average m^3 biogas per wet Metric Ton (STP)	134	m^3/tonne
Energy content of biogas	19 - 26	MJ/m^3
Energy content of food waste / Ton	2,616,000	BTU/ton
Energy content of food waste / Metric Ton	2,760	MJ/tonne

Greenhouse Gas Emissions from Waste Management

Changing the local waste management strategy can result in continuous reductions in greenhouse gas emissions. Humboldt County no longer has an active landfill, and, as a result, the County’s solid waste is transported an average of 380 miles round trip to landfills in Anderson, California, and Medford, Oregon as shown in

Figure 2.1 (HWMA, 2009). Long distance waste hauling results in diesel fuel consumption which affects the cost of local waste disposal (due to the price fluctuations of crude oil) as well as emitting 0.90 metric tons of carbon dioxide ($MTCO_2$) per trip to the landfill.[21] Using the average annual waste tonnage for Humboldt County over the last five years, the greenhouse gas emissions associated with long distance waste hauling is 4,484 $MTCO_2$ per year. Placing this waste in landfills produces methane, a greenhouse gas that has 25 times the climate forcing potential of CO_2, adding to the carbon footprint of Humboldt County's waste management approach (Forster et al, 2007). An opportunity exists to find a better waste management strategy that will result in lower GHG emissions from both landfills and waste hauling.

Diverting food waste from the landfills and managing it locally is one strategy for reducing the GHG emissions associated with waste management. Greenhouse gases trap heat in our atmosphere, effectively warming the planet and changing the climate. The observed effects of climate change are rising global land and ocean temperatures, rising sea levels, decreased snow pack, and increased severity of storm events (IPCC, 2007). The likely results from the change in climate on natural systems are increased drought, flooding, fires, as well as a loss of biodiversity (IPCC, 2007). Projected impacts to human society as a result of these changes are reduced reliable access to fresh water, changes in crop production reliability, displaced coastal communities, and increased morbidity and

[21] This calculation is based on the average round trip distance to the landfills 374 miles), the fuel efficiency of the waste hauling trucks (4.3 mpg), and the quantity of CO_2 emitted per gallon diesel fuel combusted (22.38 lbs CO_2 / gal. diesel).

mortality caused by floods, fires, drought, heat waves and shifts in vector-borne diseases (IPCC, 2007).

According to the US EPA 2006 inventory of greenhouse gas emissions in the United States, waste management activities[22] generate 2.3% of total U.S. greenhouse gas emissions (US EPA, 2009b). The Intergovernmental Panel on Climate Change reports that the waste sector[23] accounts for <5% of global greenhouse gas emissions (Bogner, J. et al., 2007). Greenhouse gas emissions associated with waste management include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Landfills produce the majority of these GHG emissions. Landfill gas emissions are derived from organic waste, such as food and green waste, breaking down in landfills under anaerobic conditions. Additional sources of GHG emissions associated with landfilling are the combustion of fossil fuels in the trucks and equipment used to move solid waste.

Food scraps decomposing in landfills are a leading source of anthropogenic methane emissions. Most other landfilled materials do not contribute to landfill gas generation as they either degrade very slowly, or are not composed of carbon (US EPA, 2009b). Over half (54%) of the solid waste generated in the United States is disposed in landfills.[24] Of this disposed portion, 18.5% is food scraps. Only a small portion (2.6%) of U.S. food waste is diverted away from landfills annually (US EPA, 2008b).

[22] In the EPA measurement, the waste sector includes landfills, waste water treatment, and composting.
[23] In the IPCC measurement, the waste sector includes landfills, waste water treatment, and waste incineration.
[24] The remaining portion of the solid waste generated in the U.S. is recycled (33.4%) and incinerated or combusted (12.6%).

Food waste is the most highly putrescible portion of the waste stream. When placed in landfills, aerobic bacteria initially decomposed the waste forming CO_2 and heat. Once the aerobic organisms have consumed the available oxygen, they die off and are replaced by anaerobic bacteria that continue to decompose the waste in the oxygen-free environment. Anaerobic decomposition of organic waste results in decomposed (or stabilized) waste and biogas, which typically consists of 50% CH_4 and 50% CO_2 by volume (US EPA, 2009b).

The CO_2 emitted from the decomposition of putrescible materials is considered to be "carbon neutral" and is not counted as a greenhouse gas. This is because it is a part of the natural cycle of plant matter taking up carbon dioxide from the atmosphere for growth, and then releasing the same amount of carbon dioxide during decomposition. Conversely, the methane generated at landfills is considered to be an anthropogenic GHG as it is not a part of the natural carbon cycle, and would not be formed if not for human activities – namely landfilling organic waste. The methane (CH_4) emitted from landfilling accounts for 23% of all U.S. methane emissions and is the largest source of anthropogenic methane emissions after "enteric fermentation" – or methane released from cows (US EPA, 2009b). The amount of methane created depends on the quantity and moisture content of the waste and the design and management practices at the site.

A study of emissions based on the decomposition of organic matter in laboratory landfills found that approximately 42% of the initial carbon content[25] in food scraps becomes methane in landfills. The amount of stored carbon was found to be ~16%, with

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[25] Food waste contains approximately 46% carbon on a dry weight basis (Zhang, 2007).

the remaining carbon released as CO_2 (Barlaz, 1997). Based on these results, researchers estimate methane emissions from landfilling organic waste to be between 0.445 and 1.44 MTCE (metric tons carbon equivalent) per wet ton of food waste (Barlaz, 1997; Brown 2007). The Chicago Climate Exchange Offset Project Protocol for Avoided Emissions from Organic Waste Disposal reports a value of 0.794 metric tons carbon dioxide equivalent ($MTCO_2e$) or, 0.214 MTCE per ton of food waste diverted from landfills (CCX, 2009). The Climate Action Registry's Organic Waste Digestion Project Protocol calculates a more conservative value of 0.308 to 0.692 $MTCO_2e$,[26] or 0.075 to 0.169 MTCE, per ton of food waste diverted from landfills. This wide range of values indicates that there exists a research gap with regards to actual landfill methane emissions.

Over the last 17 years, methane emissions from landfills have decreased by 10% due to an increase in landfill gas collection and combustion. This has offset the rise in landfill methane generation resulting from the increasing waste stream associated with population growth (US EPA, 2008b). However, the rate of increased gas collection and combustion is slowing down and no longer exceeds the rate of increasing landfill methane emissions (US EPA, 2008b). In other words, unless methane producing waste (organic waste) is diverted from landfills, this source of greenhouse gas emissions will continue to grow.

Factors which determine the quantity of methane emissions from landfills are decomposition rates of organic waste (climate dependent) and the installation and efficiency of landfill gas capture systems. The US EPA Office of Air Quality, Planning

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[26] The range of emissions reflects the decay rate of the food waste in temperate dry and temperate wet climates respectively.

and Standards has issued requirements for emissions mitigation from municipal solid waste landfills. Under these emissions guidelines, landfills constructed after 1991 that are larger than 2.5 million cubic meters are required to install gas collection systems (US EPA, 1999). Gas collection systems must be installed within five years for active cells (areas of compacted trash), and two years for closed cells (US EPA, 1999). Typically, food waste in the landfills is anaerobically broken down within 90 to 120 days, and as such, the majority of the methane formed from this particular waste is released to the atmosphere before the gas collection systems are in place.[27]

There is also uncertainty regarding the efficiency of gas collection systems. The US EPA cites an average 75% efficiency of gas collection systems,[28] but many researchers and industry professionals cite a lower capture rate (Bogner et al., 2007). In the IPCC 2006 Guidelines for National Greenhouse Gas Inventories the listed landfill gas collection efficiencies ranged from 10 to 90% depending on the landfill design, collection equipment and stage of operations (IPCC, 2006). In contrast, if organic waste is diverted to a contained anaerobic digester rather than placed in a landfill to await gas collection, nearly all of the methane will be captured and destroyed. This will substantially reduce greenhouse gas emissions at a relatively low cost and potentially with an economic

[27] Although some wastes such as food waste and cardboard decompose relatively quickly, landfill gas continues to evolve for decades (up to 50 years). The reason that landfill gas is continuously generated over long periods of time is that individual organic components in landfills decompose at different rates. For example, rubber, leather, and woody biomass decompose at a slower rate than food waste (3 months to 2 years) contributing to the overall methane generation over longer period of time (~20 years). Additional factors that dictate the rate of landfill gas generation are the level of waste compaction and moisture content in the landfill. Drier landfill conditions, i.e landfills containing less than optimal moisture content levels (45 – 60%), will have an overall slower rate of organic waste decomposition (Tchobanoglous, 2002).

[28] The EPA cites a range of 60 – 85% gas collection efficiency for landfills regulated under the Clean Air Act (40 CFR part 60) New Source Performance Standards (US EPA LMOP, 2010).

benefit. Furthermore, if methane from these sources is utilized to offset fossil fuel use, additional GHG reductions can be realized.

The impact of diverting food waste from landfills may potentially be greater than is currently estimated. There is an ongoing debate as to the most appropriate metric for measuring the true global warming potential of the different greenhouse gases (IPCC, 2009). Determining the most appropriate metric is critical for choosing the most effective policy measures to mitigate climate change. One element of the debate is the time horizon that is used to compare the impact of the distinct greenhouse gases. The Kyoto Protocol uses the metric of 100 year Global Warming Potentials to describe how different greenhouse gases compare to the climate forcing potential of carbon dioxide. This metric is subject to regular review (IPCC, 2009).

The current method for determining the global warming potential of the different greenhouse gasses is based on the radiative forcing potential of CO_2 in the atmosphere over a chosen time horizon (IPCC, 2007). CO_2 is the most prevalent GHG in the atmosphere, and as such, the global warming potential of all other GHGs is based on this reference gas. The time horizon chosen by the Intergovernmental Panel on Climate Change as well as the United Nations Framework Convention on Climate Change is 100 years. What this time frame indicates is the impact of a single pulse emission of a GHG over a 100 year time frame. Using this method, and accounting for indirect effects of methane emitted to the atmosphere, [29] methane is reported to have 25 times the global

[29] Methane emissions in the atmosphere have indirect effects such as causing changes in the tropospheric ozone and enhanced stratospheric water vapor levels. As a result, the global warming potential of CH_4 has

warming potential of CO_2 (Forster et al., 2007). Comparatively, under a 20 year time horizon, the global warming potential of methane is 72 times that of carbon dioxide (Forster et al., 2007).

Considering that humanity may not be able to adapt to the most severe rises in temperature and sea levels, the shorter time horizon may prove to be more useful in generating the policies that will promote GHG stabilization at the lowest levels possible. The time frame for mitigating the most severe impacts climate change is widely believed to be much shorter than 100 years (Barker et al., 2007). Current analysis from the Intergovernmental Panel on Climate Change shows that GHG reductions need to be immediate in order to avoid catastrophic climate change (IPCC, 2007). Reducing GHG emissions in the next few decades is critical to minimizing the cumulative impacts of climate change as well as increasing the capacity for all species to adapt to the impacts of climate change that do occur (Barker et al., 2007). According to the IPCC Fourth Assessment Report,

> "Over the next 20 years or so, even the most aggressive climate policy can do little to avoid warming already 'loaded' into the climate system. The benefits of avoided climate change will only accrue beyond that time. Over longer time frames, beyond the next few decades, mitigation investments have a greater potential to avoid climate change damage and this potential is larger than the adaptation options that can currently be envisaged" (Barker et al., 2007).

In other words, setting aggressive GHG emissions reduction goals to be realized in the next twenty to thirty years will enable the greatest chances for adaptation and climate stabilization. Choosing a 20 year time horizon would encourage the development of

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increased from 23 in the Third Assessment Report (IPCC) to 25 over a 100 year time horizon (Forster et al., 2007).

policies geared to achieve larger reductions in short-lived GHG emissions, and will direct public and private investment towards technologies that can achieve these goals. If the IPCC and other policy makers adopt this metric, the impact of reducing the methane emissions associated with waste management would become more valuable.

CHAPTER 3. TRADITIONAL FOOD WASTE DIVERSION OPTIONS

The focus of this chapter is to evaluate the food waste diversion options in Humboldt County. The US EPA promotes the following hierarchy of food waste diversion options determined as follows: source reduction, food for people (food banks), food for animals, industrial use, and composting (US EPA, 2006a). The most common method of processing diverted, post-consumer food waste is composting. However, due to the potential for generating renewable energy and minimizing emissions, municipalities and waste management agencies are now beginning to look at anaerobic digestion as an alternative.[30] Anaerobic digestion is not currently represented in this hierarchy, and part of this analysis is dedicated to ascertaining where this technology should fit in.

It is important to note here that in the waste industry, there is a distinction between "pre-consumer" and "post consumer" food waste. This distinction is important as it directly impacts the potential uses for the waste. Pre-consumer waste is food that has not been purchased, served to, or been touched by consumers. Examples of pre-consumer waste are food preparation scraps, food processing waste, and food that is near or at the expiration date. Post-consumer waste includes food scraps and leftovers generated at residences, restaurants, and institutions. Post-consumer waste is typically contaminated

[30] Jurisdictions that are currently developing plans for organic waste digester facilities include San Jose, Marin County, and Sacramento. San Jose currently has a Request for Proposals issued for anaerobic digestion of food waste, while Marin and Sacramento have completed feasibility studies for the same purpose. Additionally, Cedar Grove composting, a firm that handles all of Portland's food waste, is in the process of selecting a digester technology to stabilize the food waste before composting to reduce volatile organic compound emissions (Cedar Grove, 2008 personal communication).

with plastics, silverware, and other materials. The removal of these contaminants raises the cost and energy inputs required to utilize this waste stream.

This study is focused on dealing with food waste that is not suitable for humans or animals and is primarily post-consumer waste. Surveys of local grocery stores, food banks, and pig farmers helped to determine the food waste diversion options already in place. These facilities were visited by HWMA staff, and the managers or owners were asked a series of questions that can be seen in Appendices A through C. A formal telephone survey of California composting facilities was used to gain an understanding of the requirements and challenges of processing food waste. Survey questions and responses can be seen in Appendices D and E. The results of this research are presented in the sections that follow.

Grocery Stores

HWMA staff members surveyed local grocery stores to determine the disposal methods for the food waste that is generated onsite. The stores surveyed were Costco, Winco Foods, Safeway, Murphy's Market and Eureka Natural Foods. The stores produce a large amount of food waste, the majority of which is already diverted.

All of the stores surveyed have butcher shops that produce meat cuttings in large quantities. The meat scraps are sold to rendering companies or are ground up and sold as ground beef. Fat cuttings are also sold to rendering companies by all excepting the Murphy's Markets, which give these cuttings to pig farmers.

The bakery departments of the stores surveyed produce bread, of which some goes unsold. The bakeries give this bread to various food banks or to the Eureka Rescue Mission. The pizza or deli departments of these stores all have leftover cooked food and uncooked dough. Many stores have less than fifteen pounds of leftovers and discard it as garbage. The Murphy's Market and Safeway chains give their unsold deli food to various food banks.

Food Banks

Food banks glean significant amounts of food from grocery stores as well as from restaurants that have excess prepared food at the end of the night. They accept packaged or ready-to-eat food that is about to expire, as well as bread that goes unsold from bakeries. Food banks can only accept pre-consumer waste that is fit for human consumption. While all food banks have expressed the readiness to accept more food donations, this diversion option can only absorb a relatively small part of the remaining food waste stream.

Pig Farms

Food from grocery stores and area restaurants that is not fit for food banks can be diverted to pig farms; however, there is insufficient local capacity on these farms to divert the magnitude of food waste in the County. Humboldt County has two permanent, medium-sized pig farms and a few small occasional pig farmers. The two permanent farms are the Sheriff's Work Alternative Program (SWAP) farm and Harold Davison's farm. They have 38 and 170 pigs respectively and both operate near Fortuna. The SWAP farm accepts three cubic yards of pre-consumer food waste daily. The Davison farm receives two cubic yards of food scraps daily, except in the summer time when it takes in three cubic yards per day with the inclusion of food waste from the Ferndale Farmer's Market. The Davison farm primarily accepts pre-consumer waste. The large pig farms surveyed stated that they are at capacity for accepting food waste and are not looking to expand their operations. This is due to the limited market for pork in Humboldt County, as well as the time and effort required to collect and remove the undesirable components of the pre-consumer food waste (onions, peppers, and citrus) which pigs don't like.

Four small pig farmers were contacted. These farmers accept pre-consumer food waste in the form of vegetables, fruits and bread. These small farmers are all raising pigs on a temporary basis for money, food, or as a 4-H project.

Post-consumer waste is less desirable as a pig food due to the labor and energy required to sort out contaminants and heat treat the waste. In order to protect the pork industry from the potential stock devastation caused by the spread of "foreign animal diseases" such as foot and mouth disease, hog cholera, and African swine fever, federal lawmakers passed the Swine Health Protection Act (1980). This law requires anyone feeding food scraps to pigs to obtain a permit and heat treat the waste to kill disease-causing organisms (Public Law 96-468, 1980). In California, heat treatment is defined as heating post-consumer waste to 212° F for two hours, with agitation "to heat throughout" (CDFA, 2009). This pre-treatment adds considerable cost to the otherwise free pig food.

Compost

Compost is the humus-like product resulting from the controlled biological decomposition of organic material. Properly composted material is sanitized through the generation of heat and stabilized to the point that it is beneficial to plant growth (USCC, 2008). Composting is the most common form of large scale post-consumer food waste diversion. Finished compost makes a valuable soil amendment, and when mixed into the soil promotes a proper balance between air and water in the soil, reduces erosion, provides a slow-release fertilizer to nourish plants, and can be used to bio-remediate contaminated soils (USCC, 2008). Finished compost can also be used as a bio-filter for odor and emissions control.

Composting is the aerobic decomposition of organic matter. During composting, microorganisms use organic matter (carbon) as a source of energy and food. The microorganisms convert the easily decomposable carbon into more microbial cells and, as a result of their growth and activity, produce carbon dioxide, heat, water vapor, and a nutrient rich humic material (compost). Through this process, complex molecules such as carbohydrates, fats, and proteins are broken down to release nutrients and energy. This can be seen in the general chemical equation for the aerobic decomposition of glucose:

$$C_6H_{12}O_6 + 6O_2 \Rightarrow 6CO_2 + 6H_2O + heat$$

Compost microorganisms require a balance of carbon, nitrogen, water and oxygen to survive. Additional factors affecting the microbial environment are temperature, pH, and the absence of toxic materials that may inhibit their growth (US EPA, 1995). Compost piles need to be monitored and managed in order to maintain optimal conditions for the efficient microbial decomposition of organic waste. Figure 3.1 shows the general steps necessary for municipal scale composting of food waste.

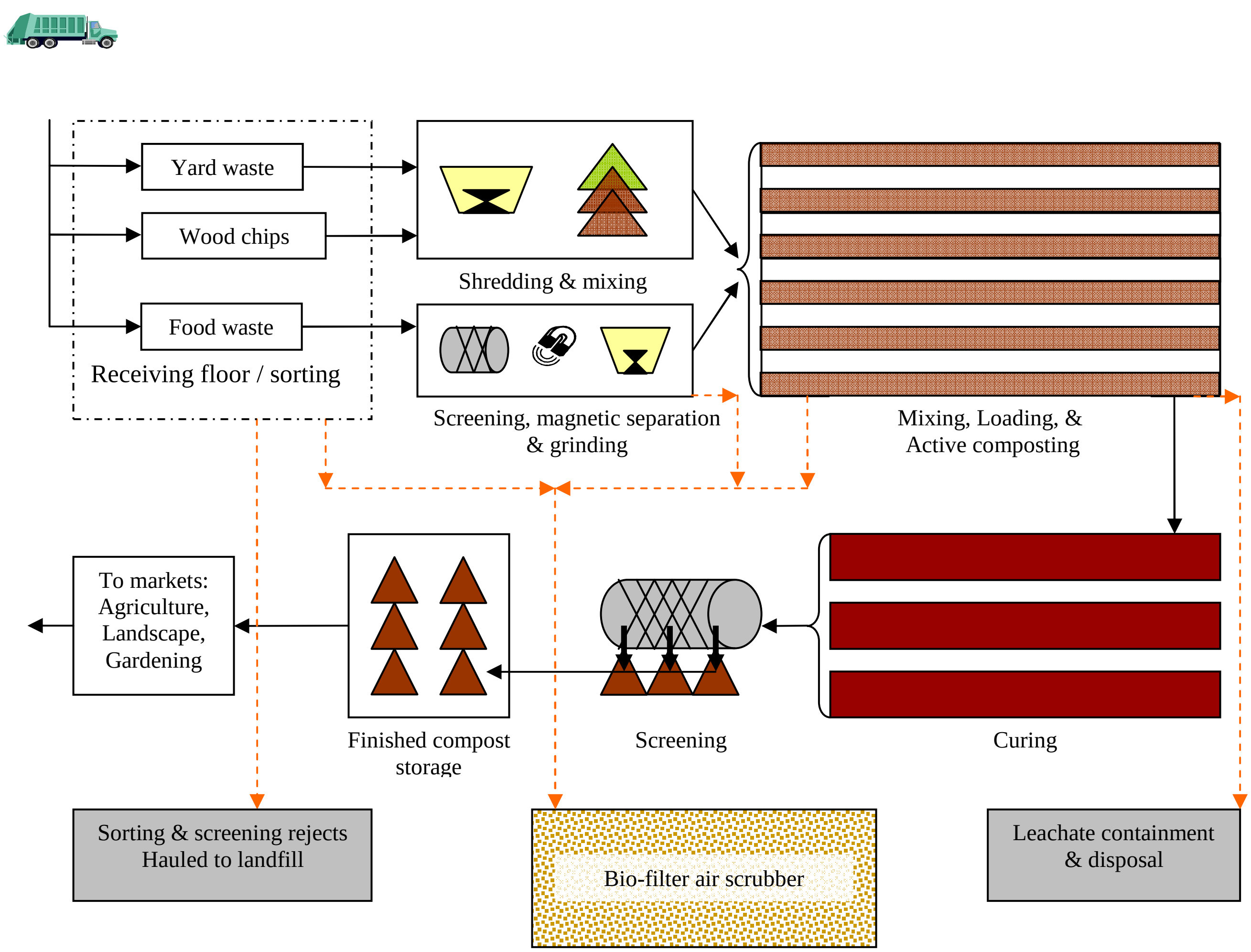

Figure 3.1 Flow diagram of the composting process. The black, solid lines represent the flow of the organic materials such as woody biomass, yard waste, and food waste. The orange dashed lines represent waste products that require further treatment or disposal.

The municipal-scale composting process includes the following steps:

- **Receiving**: Incoming material is inspected for contamination. High levels of contamination can reduce the value of the finished compost and limit the marketability of the stabilized product (US EPA, 1995).

- **Shredding/grinding**: The material is shredded to reduce particle size. Particle size is important for rapid microbial decomposition of the material. Particles need to be both small enough to optimize decomposition,[31] yet large enough to maintain spaces for oxygen to circulate (US EPA, 1995).

- **Mixing**: Shredded materials need to be blended to achieve an optimal carbon to nitrogen ratio (C:N) and moisture content for aerobic decomposition. A C:N ratio of 30:1 is ideal (US EPA, 1995).[32] Optimal moisture content is 50 – 60% of total weight (US EPA, 1995).[33] Composting food waste requires a bulking agent such as wood chips or woody biomass to balance out the C:N ratio and absorb some of the moisture to provide air spaces to maintain aerobic conditions.

- **Loading:** The mixed material is placed into windrows or vessels for processing. Front-end loaders or bag loaders are used to move the shredded material.

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[31] Smaller particles have a higher surface-area to weight ratio which increases the amount of food available to the microorganisms.

[32] Too much carbon in a compost mix will retard the decomposition process, too little can result in odors (U.S. EPA, 1995).

[33] Moisture is essential for microbial growth, but too much water can result in leachate formation, the impediment of oxygen transfer, odors, and anaerobic pockets in the waste (U.S. EPA, 1995).

- **Processing:** Processing involves aerating the piles and monitoring the temperature and moisture content. Aeration can be accomplished by mechanically turning the compost piles with front-end loaders, specialized turning equipment, or by forcing air into piles via pipes and blowers. Aeration is used to evenly distribute oxygen, nutrients, and moisture throughout the compost piles. Aeration can also be used to control the temperature and monitor the particle size (decomposition) and maturity of the compost (US EPA, 1995). Compost operators must monitor the temperature and moisture content to ensure uniform decomposition. The ideal temperatures range from 32º – 70º C (90º - 160º F) (USCC, 2009). If the pile gets too hot, thermal destruction of the microorganisms will occur; if the pile is too cold, the metabolism of the microorganisms is adversely affected. Additionally, a pile that is too hot can present a fire hazard. Water content is monitored to ensure a proper environment for microbial activity as well as mitigate the risk of fire.

  Aerating the piles during the active composting phase increases the pile temperature. The active composting phase can range from several days to several weeks depending on turning frequency, aeration and ambient temperatures (US EPA, 1995). During the active processing phase of composting, temperatures are usually in the thermophilic range (over 40 º C or 105 º F) and the pile volume is substantially reduced. This high temperature is a direct result of the microbial activity and results in sanitizing the compost by killing pathogens and sterilizing weed seeds (US EPA, 1995). Additionally, the California Code of Regulations (CCR) requires compost facilities to adhere to a process of pathogen destruction. During this period the mechanically turned material mush be brought to 55ºC (131°F) for 15 days and turned at least five times (CCR Title 14). Forced aeration systems in enclosed compost systems must reach and maintain temperatures above 55ºC for at least three consecutive days (CCR Title 14).

- **Curing:** Once the microorganisms have consumed and stabilized most of the easily decomposable carbon, the temperature drops indicating that the curing phase has begun. The curing phase can last for several weeks to six months (US EPA, 1995). During this phase, the final decomposition and biological stabilization takes place. Turning is not required during this phase; however, it is important to continue to maintain aerobic conditions and appropriate moisture content. The curing phase is important as unfinished compost can deprive roots of oxygen and subject the plants to heat that can retard their growth.

- **Screening:** Screening can be done before or after the curing process. The compost is screened to remove residual chunks of woody biomass as well as non-compostable elements. The large woody biomass is returned to the receiving pile, and the non-compostable materials are landfilled.

- **Storage and/or bagging:** Composting facilities either sell the compost directly from their site, or bag the compost for sale at markets.

There are three main types of compost systems: turned windrows, aerated static piles, and in-vessel systems. Windrows are long rows of shredded organic material (e.g., food scraps, grass clippings, and woody biomass) that are turned regularly by either manual or mechanical means. These piles are usually four to eight feet tall and 14 to 16 feet wide (US EPA, 2010). These dimensions are ideal for maintaining sterilization temperatures and for allowing oxygen to penetrate to the center of the piles. This composting method can accommodate large quantities of organic materials, but it cannot accommodate large amounts of meat, grease, or liquid wastes without frequent turning and careful temperature and moisture control (US EPA, 2010). In arid climates, windrow piles may need to be covered to reduce evaporation. In moist climates, windrow piles may need to be covered in order to prevent leachate formation and maintain stable moisture content in the piles (US EPA, 2010). Turned windrow compost piles can be a source for odors and dust, and usually require large tracts of land (US EPA, 2010).

Aerated static piles are large piles of material that are not placed in long rows and are not turned. Aerobic static piles can be passively aerated by incorporating loosely piled bulking material (such as woodchips) or by placing the piles over a network of perforated pipes to draw air into the piles. This method works well for large quantities of homogenous materials, but is not suitable for animal wastes, grease, or liquid wastes (US EPA, 2010). Aerobic static pile composting requires three to six months for waste stabilization and may result in increased odors, volatile organic compounds, and/or GHG emissions.

In-vessel systems consist of an enclosure completely surrounding the compost and forced aeration. The vessels can be a large drum, silo, concrete trenches, long tubular bags, or membrane covers. The key composting conditions (temperature, aeration and moisture) are closely monitored and controlled when using in-vessel systems. In-vessel systems can compost large quantities of waste in less space than turned windrows and can process nearly any type of organic waste. In-vessel systems produce very little odor or leachate as the system is completely enclosed and controlled. A curing phase lasting several weeks is still required once the material is removed from the vessel system.

Diverting organic “waste” away from landfills to compost facilities is essential for maintaining long-term soil fertility. Recycling nutrients from decaying matter “helps ensure the stability of natural systems over time by linking the processes of synthesis (build-up) and degradation (breakdown) in natural systems” (CalRecycle, 2010b). Composting organic waste can help societies avoid the environmental impacts of accumulating nutrients where they are not needed, and at the same time reverse the depletion of nutrient resources in the soils where they are needed. The following section describes considerations for composting food waste diverted from landfills.

Composting Food Waste

Composting is the most common form of large-scale food waste diversion. HWMA staff conducted a survey of the food waste compost facilities in California. The majority of these facilities are located far from population centers (where the waste is generated) in order to access inexpensive, large tracts of land, as well as for NIMBY[34] and odor issues associated with processing food waste. The majority of the food waste composting facilities surveyed utilize a windrow composting process on compacted earthen foundations. Composting facilities which do not use windrows use in-vessel systems in the form of bag systems made of either plastic or Gore-Tex.

Municipalities have historically viewed windrow composting as the cheapest and lowest-risk option for large-scale food waste diversion. This diversion paradigm appears to be changing with implementation of more stringent air quality regulations in California. As of 2003, the South Coast Air Quality Management District passed rule 1133.2 that requires all co-composting[35] operations to develop a plan to reduce emissions of ammonia and Volatile Organic Compounds (VOCs) by 80% (SCAQMD 1133.2, 2003). The SCAQMD issued this rule as part of an effort to reduce the total amount of VOCs in the district air basin. VOCs are an air quality issue because they are a precursor to smog formation, are the main source of objectionable odors, and are often toxic.

In 2007, CalRecycle measured VOC emissions from compost that contained green waste and a combination of both green waste and food scraps. The results of this research indicate that adding food waste to green waste results in higher (2-3 times) VOC emissions than composting green waste alone (CIWMB, 2007). Additionally, the data showed a significant spike in emissions during turning events. Compliance with this rule will require that all food waste composting will have to be enclosed or covered with layer

[34] NIMBY stands for "Not in My Backyard" and describes opposition by residents to new proposals or development close to where they live.
[35] Co-composting is the composting of two or more materials with different characteristics (e.g., food waste and green waste)

of finished compost[36] to control emissions. The cost of open air composting will be significantly increased using either of these emissions control measures.

Currently, research is underway to quantify the net greenhouse gas emissions impact of diverting organic waste from landfills to composting facilities (Brown et al., 2008; CIWMB, 2008). Emissions reductions can include not only the avoidance of methane produced at landfills, but also the reduced emissions from fossil fuels used to produce synthetic fertilizers and to pump water. Although significant GHG emissions reductions can be achieved when organic waste is diverted to composting, recent research indicates the presence of fugitive greenhouse gas emissions from the composting process. Researchers found emissions of methane (CH_4) and nitrous oxide (N_2O) were released from compost piles due to anaerobic and semi-anaerobic zones in the piles (Fukumoto, 2003; He, 2000; Hobson, 2005; Smet, 1999). Under the IPCC default (Tier 1) methodology for greenhouse gas accounting, estimates of CH_4 and N_2O emissions are 0.03 - 8g CH_4 and 0.06 - 6g N_2O per kg of waste composted (IPCC, 2006). The variability of waste composition and operating parameters is cited as the basis of this uncertainty. This wide range of values highlights the need for additional measurements of these emissions in order to assess the true GHG reduction potential of this method of organic waste diversion.

[36] The CIWMB study investigated effective emissions management practices and found that a cover layer of finished compost one foot thick significantly reduced emissions and increased the level of waste stabilization. The authors posited that the efficacy of this method is the result of the large populations of aerobic microorganisms (present in the finished compost bio-filter) being mixed into the compost pile during turning.

Regardless of the uncertainty, the avoided methane emissions achieved by diverting this waste from the landfills far outweighs the emission impacts of composting operations (Brown, 2008). As mentioned earlier, organic waste in landfills creates methane – a greenhouse gas with 25 times the global warming potential of CO_2. When this same waste is composted, the primary end products are CO_2 and heat. This CO_2 is not considered to be a GHG as it is part of the natural carbon cycle (i.e., the same carbon dioxide that is released was taken up from the atmosphere during plant growth and is part of the natural cycle). The CO_2 emissions from the equipment used in the composting process are considered to be anthropogenic greenhouse gasses (contributing to climate change) as they would not exist in the natural carbon cycle.

Challenges associated with large-scale food waste composting include: large land area required for processing, odors, and leachate formation. In Humboldt County, there are additional challenges. First, there is limited availability of flat land suitable for composting. Second, the high levels of annual rainfall would require a covered facility in order to maintain optimal processing temperature profiles. Finally, and perhaps most significantly, there is a limited amount of green waste with which to compost food waste. Humboldt County is unusual in that it has three operating biomass power generating plants. These plants were built when the lumber industry was thriving, and are now hungry for fuel. These plants operate on wood waste from the local lumber industry and transfer station as well as wood chips from out of the County that are trucked and barged in. While these plants provide 47% of Humboldt County's electrical power supply, they also absorb much of the green waste available for composting (RCEA, 2005). The

HWMA Mad River Composting Facility processes 5,000 tons per year of green waste (HWMA, 2009). Composting the regional food waste with the existing green waste supply would require at least twice as much green waste as is currently diverted to the composting facility. Additionally, odors from food waste composting would make site selection difficult. For these reasons, anaerobic digestion was analyzed as an alternative to composting. The next chapter describes the anaerobic digestion process and considerations relating to anaerobically digesting food waste.

CHAPTER 4. ANAEROBIC DIGESTION

Anaerobic Digestion is the decomposition of organic matter by microorganisms in an oxygen-free (anaerobic) environment. Anaerobic digestion is a natural process occurring in landfills, swamps, lagoons, oil fields and in the digestive systems of humans, cows and termites. Anaerobic bacteria cultures can be found in mud, under still water, in fresh manure or excrement, under an unturned compost pile, or any place where organic matter has been sitting unexposed to air (House, 2006).

Anaerobic digesters are air-tight containers. These containers can be in the form of a covered lagoon, vertical cylinders or horizontal tanks and bladders. Digester system components typically consist of pumps, a mixing and heating system, and a gas collection system. In the United States, anaerobic digestion is most commonly employed at wastewater treatment plants to reduce and stabilize municipal wastewater sludge. Both the Arcata and Eureka wastewater treatment plants use digesters as part of their wastewater treatment operations. Digesters are also utilized to treat animal waste at dairies and pig farms. In the US alone, the EPA reports 111 farm digesters in operation as of 2007 (US EPA, 2007). Household-scale digesters have been employed for decades in the rural areas of China and India for treating animal waste and producing biogas (CIWMB, 2008a). The biogas is used primarily for heating and cooking purposes.

Anaerobic digestion and composting processes are similar in that they both reduce and stabilize organic matter producing a valuable soil amendment. The two processes differ in terms of the energy products of the microbial waste conversion activity. When organic material is aerobically composted, the pile temperature is often 70°C (160°F) during the most active period. The energy released from the decomposition of organic matter escapes to the atmosphere in the form of heat, and the result is a stabilized, pathogen-free soil amendment. When similar organic materials are anaerobically digested, no appreciable heat is produced, and much of the energy is locked up molecularly as methane (in biogas).

Biogas from anaerobic digesters typically consists of ~60% methane, ~40% carbon dioxide[37] and trace amounts (<1%) of water, ammonia (NH_3)[38] and hydrogen sulfide (H_2S).[39] Water and H_2S are generally removed in a gas treatment step before the biogas is utilized. The biogas can be used for direct heating,[40] generating electricity,[41] or as a vehicle fuel.[42] Biogas can also be purified and injected into the utility pipeline gas grid.[43]

The other end products of the digestion process are the remaining liquid (digestate) and the residual solids. The liquid portion digestate can be separated from the

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[37] Biogas from anaerobic digesters contains more methane than biogas generated from landfills. This is due to the contained nature of the digester. Because the CO_2 remains in the digester (versus escaping to the atmosphere), a portion will be combined with the hydrogen, that is also produced, to form additional methane (CIWMB 2008a).
[38] Ammonia can act as a process inhibitor if produced in high concentrations; in lower concentrations ammonia can act as a buffer to help correct an acidic condition in the digester (House 1991).
[39] Hydrogen sulfide is a combustible gas, and in combination with water vapor forms a corrosive vapor of sulfuric acid.
[40] Examples of direct heating include space, water, and industrial process heating.
[41] Electricity can be generated from biogas via an internal combustion engine, a micro-turbine, or a high-temperature fuel cell.
[42] Biogas can be purified and compressed to fuel a compressed natural gas vehicle.
[43] Pacific Gas & Electric, the local utility provider, has only recently (as of 2008) begun to accept dairy waste biogas into the natural gas pipeline network (http://www.pge.com/about/news/mediarelations/newsreleases/q1_2008/080304.shtml). While cleaning and injecting biogas into the grid is technically feasible, PG&E has yet to establish a policy for accepting food waste derived biogas into their network.

solids through gravity separation (settling), gravity belt thickeners, drying beds, or other drying processes. Organic waste digester systems that do not include wastewater treatment plant sludge produce a digestate that can be used as a liquid fertilizer. Furthermore, the residual solids from these “stand alone”[44] systems can be co-composted with green waste to produce a nutrient-rich soil amendment.

Anaerobic Digestion Process

The anaerobic digestion process is shown graphically in Figure 4.1. The rate of anaerobic digestion is directly tied to the temperature of the digester. Digestion occurs at three main temperature ranges from cold or psychrophilic, 15° – 25°C (59° - 77°F), warm or mesophilic, 25° – 45°C (77°-113°F), and hot or thermophilic, 45° – 55°C (113°-157°F) (House, 2006). The digestion time for each of these temperature ranges, respectively, is 90 to 100 days (psychrophilic), 25-35 days (mesophilic), and 10-15 days at thermophilic temperatures. The majority of digesters in use today are operated at mesophilic temperatures where the microorganisms are more robust and better able to tolerate small fluctuations in environmental conditions. Although operators can achieve a faster digestion rate and increased pathogen destruction at thermophilic temperatures, the microorganisms that thrive at higher temperatures are more sensitive to toxins, changes in temperature, pH, and feedstock (House, 2006).

[44] Stand alone refers to organic waste digestion separate from municipal sludge digestion. When organic waste is digested with municipal sludge, the process is considered “co-digestion.”

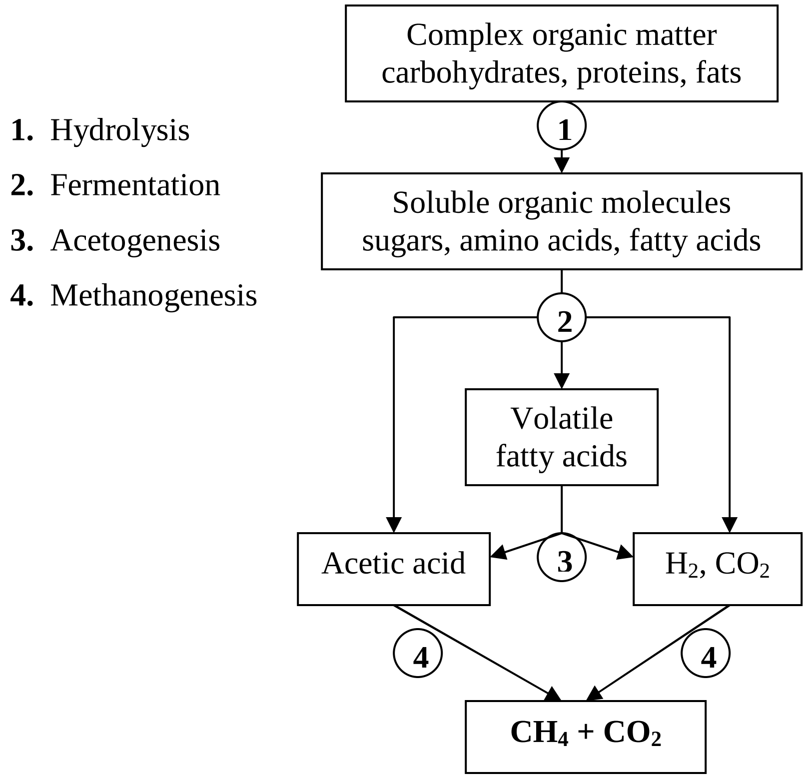

Figure 4.1 Anaerobic digestion of organic matter. Adapted from: U.S. Environmental Protection Agency Region 9 Waste Programs, *Organics: Anaerobic Digestion Science* (2008).

The anaerobic digestion process can be broken down into the following steps:[45]

1. Hydrolysis: Long chain organic molecules are broken into smaller molecules via extra-cellular enzymes released by fermentative bacteria. These enzymes are substrate-specific, and therefore different wastes will have different hydrolysis rates. In this phase, fats are converted to fatty acids, proteins into amino acids, and complex

[45] The chemistry of anaerobic digestion is well documented in the literature. This description was adapted from the US EPA Region 9 Waste Programs webpage titled *Organics: The Anaerobic Digestion Science* (2009), a report titled *Current Anaerobic Digestion Technologies Used for Treatment of Municipal Solid Waste* commissioned by the CIWMB (2008a), and The Biogas Handbook by David House (2006).

carbohydrates such as polysaccharides and cellulose are converted into simple sugars (Metcalf and Eddy, 1991).

2. Acidogenesis: The products (monomers) of the hydrolysis step are immediately absorbed by the bacteria known as "acid formers" and are digested to produce volatile fatty acids such as lactic, butyric, propianoic, and valeric acids. This step is also known as fermentation.

3. Acetogenesis: In this step, bacteria consume the volatile fatty acids to form acetic acid, CO_2 and hydrogen (H_2). The acido- and acito-genesis stages are often considered one step. These bacteria prefer a pH of 4.5 to 5.5 (slightly acidic) and are less susceptible to variations in temperature, pH, loading rate and feedstock.

$$C_6H_{12}O_6 + 2H_2O \Rightarrow 2CH_3COOH + 4H_2 + 2CO_2$$

4. Methanogenesis: Methanogenic bacteria consume the acetic acid, hydrogen and some of the carbon dioxide to form methane. The two main conversion pathways are acetate conversion and carbon dioxide reduction by hydrogen. The majority of the reactions involve the conversion of acetate to methane and carbon dioxide. The conversion pathways are described by the following chemical equations:

$$4CH_3COOH \Rightarrow 4CO_2 + 4CH_4$$

$$CO_2 + 4H_2 \Rightarrow CH_4 + 2H_2O$$

The methanogenic bacteria prefer a pH between 6.5 and 8.5, and at a pH of 5.5 the methane formers are not active (House, 2006). Additionally, the methanogenic bacteria are more susceptible to upset[46] by changes in temperature, feedstock, and loading rate. The metabolic rate of these bacteria is slower than the metabolic rate of the preceding bacteria and, as such, the overall loading rate of anaerobic digesters is limited to the metabolic rate of the methanogenic bacteria.

Anaerobic Digester Configurations

There are many different types of anaerobic digestion systems. The three main variations include wet vs. dry systems, single phase vs. multi phase, and stand alone vs. co-digestion. Wet, or low solids, digestion refers to processing a waste that has been diluted with water, and/or has a total solids content below 10 -15% (i.e., a moisture content above 85%). Wastewater treatment plant digesters are examples of wet digestion systems. Dry, or high solids, digestion refers to digester systems where little to no water is added to the waste, and the total solids concentration is greater than 15%. Dry digestion is currently used to treat solid organic wastes in Europe. Wet digester systems require pre-treatment to remove inert solids[47] as well as homogenize the waste. Dry digester systems require purchasing heavy duty pumps or augers, and, due to the density of the material, can require inoculation of the incoming waste with a portion of the

[46] Digester upset occurs when the methanogenic bacteria die and stop producing methane, causing the entire digester to turn acidic.
[47] Inert solids can damage pumps and mixing equipment as well as clog pipes in digester systems.

residual digestate. In Europe, dry digestion has become more prevalent for organic solid waste digestion comprising 60% of the installed capacity to date (CIWMB, 2008).

Single phase digesters consist of one tank that houses both the acid forming and methane forming bacteria. The loading rate of single phase digesters is limited by the rate at which the methane formers can metabolize the volatile fatty acids produced during the rapid hydrolysis and acidification stage. Multi-phase systems utilize two or more tanks to separate the acid forming and methane forming stages of digestion. The goal of a multi-phase system is to achieve a higher overall organic waste loading rate by allowing the faster initial decomposition of the acid formers to be separated from the slower metabolism and low pH sensitivity of the methane formers. Single phase digester systems typically have a lower capitol cost than multi phase systems, and are more commonly used for all types of waste digestion systems (CIWMB, 2008).

Finally, anaerobic digestion systems can be distinguished by whether multiple waste streams are digested together or separately. This distinction is especially significant when organic wastes are digested with municipal wastewater solids. Because wastewater sludge can contain heavy metals and pharmaceuticals, comingling other wastes with this waste stream can decrease the value of the residual stabilized material. Stand alone systems in this case refer to systems that digest organic solid waste (including food waste and industrial food processing wastes) in digester vessels that do not accept municipal wastewater sludge. Co-digestion refers to the digestion of two or more distinct waste streams. In this case, co-digestion is referring to the addition of organic solid waste to municipal wastewater sludge and/or manure digester vessels. It should be noted here that some “stand alone” organic solid waste digester systems may add manure to the organic waste to help stabilize the digestion process. The digested residual resulting from stand alone organic waste digester systems and/or the mixture of manure and solid organic waste has a higher market value (and a larger market) than the residual from wastewater treatment plant co-digestion. The advantage of co-digestion is a lower initial capital cost due to the use of existing equipment.

All of the aforementioned digester designs can be operated at either mesophilic or thermophilic temperature regimes. The following section describes the key considerations pertaining to the anaerobic digestion of food waste regardless of the system chosen.

Anaerobic Digestion of Food Waste

Organic waste feedstocks need to be assessed to determine their suitability for anaerobic digestion. Some of the factors to consider are:

- Volumes and seasonal variation: Anaerobic microorganisms are sensitive to changes in feedstock. Changing the feedstock can cause a slow-down in processing time while microorganism populations suited to metabolize the new waste establish their populations.

- Total Solids (% TS) and moisture content (MC): Total solids is a measure of the solid matter in a substrate when the moisture, or water content, is taken out (House, 2006).

- Volatile Solids (% of TS): The portion of the solid organic material (TS) that is available for conversion to biogas (House, 2006).

- pH: Substrates with a near neutral pH are ideal for digestion. Acidic wastes such as cheese whey will need to be blended with other materials or buffered with a base such as lime (House, 2006).

- Carbon to Nitrogen ratio (C:N): Microorganisms, like other organisms, have dietary needs to remain healthy. In general, the ideal C:N ratio (mass ratio) is 25-30 for anaerobic microorganisms (House, 2006).

- Salt content: High salt contents can inhibit the methanogenic process (House, 2006).

- Decomposition rate: Organic wastes such as fats, proteins, and carbohydrates all decompose at different rates. Bench-scale digestion can be used to test the digestibility of different waste streams (Zhang, 2007c), and is especially important for heterogeneous wastes.

- Potential issues with stirring or pumping: Some wastes are more prone to forming a “scum” layer that can clog pipes (House, 2006). Other wastes such as oyster shells are hard on pumps (Grey et al., 2008).

- Contaminants: Contaminants such as plastics and metals can take up valuable digester volume, can damage equipment such as pumps (Grey et al., 2008) and can reduce the value of the residual soil amendment.

- Pre-processing requirements: Preprocessing consists of contaminant removal and size reduction to prepare the food waste for digestion. Highly contaminated food wastes require pre-processing to remove inert contaminants. Pre-processing steps can include visual inspection, contaminant removal, grinding, screening, magnets and/or density separation (CIWMB, 2008a). Increasing the number of pre-processing steps reduces the net energy[48] that can be gained from an anaerobic digestion process.

In general, when complex waste streams such as the organic fraction of municipal solid waste or industrial wastes are to be treated through anaerobic digestion, laboratory assays and pilot collection and digestion runs are necessary to determine many of the above parameters. The next chapter compares anaerobic digestion and composting as methods for food waste diversion and stabilization.

[48] The net energy is the amount of energy generated by the system minus the energy required to operate it.

CHAPTER 5. COMPARISON OF COMPOSTING AND ANAEROBIC DIGESTION

Until recently, local decision makers and waste management agencies have had little debate about the relative benefits and costs of composting versus anaerobic digestion. Composting has traditionally been seen as the best management practice for diverting municipal-scale food waste from the landfills. This waste stream is primarily post-consumer, and is contaminated with plastics, silverware, paper, Styrofoam and other materials. The heterogeneous nature of post-consumer food waste requires a diversion program that can effectively convert this waste into useful products. For these reasons, composting, and more recently, anaerobic digestion, are utilized as a means to divert post-consumer food waste from the landfill.

Anaerobic digestion and aerobic composting utilize natural processes that reduce the volume of organic matter and stabilize it. The costs of establishing either system depend on the technology chosen, the characteristics of the waste feedstocks, the climate, and the overall goals of the diversion program. The cost comparison in this analysis is based on a 10,000 ton / year facility. The underlying assumptions and system components are discussed in CHAPTER 8 (Methodology), and CHAPTER 9 (Results).

Composting and anaerobic digestion systems rely on microorganisms, involve some amount of pre-processing, and require a carbon to nitrogen ratio of approximately 30:1. The two processes differ in terms of net energy balance, air emissions, footprint, and process time. A synopsis of these differences can be seen in Table 5.1

Table 5.1 Comparison of anaerobic digestion and in-vessel composting for a 10,000 ton / year facility

Metric for Comparison	Anaerobic Digestion	In-vessel Composting
Cost		
Capital cost for 10,000 ton per year facility ($)	$8 million	$6 million
Life Cycle Cost over 20 years ($)	$9 million	$14 million
Energy		
Diesel fuel (gal / ton)[49]	0.8	1.6
Electricity (kWh / ton)	-210	58
Other parameters		
GHG emissions from processing equipment ($MTCO_2$/year)	-560	330
Fugitive GHG emissions from process (%)	<2% of initial C during start up and maintenance	1.5% of initial N (N_2O), 2.5% of initial C (CH_4)[50]
Land requirement (acres)	<2 acres	>4 acres
Process time (weeks)[51]	3 to 7	8 to 24

The following sections contain the details that underlie the energy and other parameter comparisons. Note that this comparison is based on in-vessel composting technology only. This approach was chosen due to the high regional rainfall levels as well as the known challenges associated with permitting and finding a site for an open

[49] The composting process relies on heavy equipment such as loaders, turners, screens, and grinders that are powered by diesel fuel. The anaerobic digestion process requires less heavy equipment and relies more on equipment powered by electricity which is generated from the biogas. In this analysis, the fuel use for the anaerobic digester is assumed to be half of the fuel used by a composting operation. The diesel fuel use value for in-vessel composting was derived from the average value given by composting system vendors in response to an HWMA enquiry.

[50] These values are based on manure and woody biomass composting. More research is needed to quantify the fugitive GHG emissions potential from food waste composting.

[51] The high end estimates represent the time allocated for curing in addition to processing.

windrow food waste composting facility. An in-vessel system will be able to control emissions, odors and leachate and is therefore more likely to be acceptable to both regulatory agencies and the community.

Net Energy Balance

Diesel fuel use and electricity consumption negatively impact the operating cost, carbon footprint, and net energy balance of both anaerobic digestion and composting processes. The following section describes the energy inputs and outputs of both composting and anaerobic digestion systems.

The composting process requires the use of loaders, grinders, pile turners and trommel screens. The quantity of diesel used at a compost facility is directly related to the type of composting system and processing equipment chosen, as well as the annual throughput of organic material. The fuel use estimates used in this analysis are based on an estimate generated by The Recycled Organics Unit (ROU) of the Department of Environment and Conservation in New South Wales, Australia, and from information provided by in-vessel compost system vendors. The ROU recently published a life cycle analysis of windrow composting and reported that an average of 5.5 liters of diesel fuel / metric ton (1.3 gallons per ton) of waste are required for composting (ROU, 2007). The authors compiled the fuel use for key composting process steps and calculated an estimate that was lower than a previously cited US EPA estimate of 1.7 gallons diesel /

ton (7.0 liters of diesel fuel / metric ton) (ROU, 2007).52 Estimates provided to HWMA by in-vessel composting system vendors ranged from 1 to 2.4 gallons diesel / ton with an average of 1.5 gallons / ton (HWMA, 2010).53 Electricity is used to power blowers and monitoring equipment in in-vessel systems. The range of electricity use provided in the HWMA in-vessel composting vendor was 12 to 99 kWh / ton of material (HWMA, 2010). The average value was 58 kWh / ton of material.54 The average of all energy use estimates, 1.6 gallons / ton and 58 kWh / ton, were used to calculate the annual fuel costs and GHG emissions in this analysis. Due to the combination of energy inputs needed for processing and the dissipation of the heat energy during decomposition, composting has a negative net energy balance.

Anaerobic digestion has a positive net energy balance, as the digestion process produces more energy than is required for the processing operations. Like composting, some machinery is required for moving the material, size reduction, and removing contaminants. In addition, digesters systems utilize pumps, mixers, and heating systems. However, because the energy content in the waste is greater than the energy required for processing,[55] this equipment can be powered by electricity generated from the biogas

[52] As a comparison, the compost operator at the HWMA Mad River Compost facility estimates that grinding one ton of green waste requires one gallon (3.8 liters) of diesel fuel. In addition to grinding, the ROU estimate listed in this section also includes fuel used for pile formation, turning and screening.

[53] HWMA released a Request for Information to in-vessel compost vendors to evaluate a food waste composting program for Humboldt County. All values listed in this section for in-vessel systems come from the 10 responses HWMA received from this enquiry.

[54] It should be noted here that some processes rely more on diesel fuel for mechanical turning, while others use more electricity for forced aeration. The average numbers are useful to gauge the magnitude of the fuel used in these processes.

[55] A local example of this is the Eureka wastewater treatment plant. The plant generates 43% of its entire plant electrical demand (including all aerobic wastewater treatment train processes, pumping, lighting,

produced by the digesters. A study on anaerobic digestion of food waste in Europe found that 165-245 kWh of excess renewable energy is generated per ton of material digested (DeBaere, 2000). The amount of net excess energy varies depending on the amount of energy needed to operate the pre-processing and processing equipment. The excess energy can be used to power onsite loads, or can be sold to the local electric utility provider.

An additional benefit of the energy produced from anaerobic digestion is that it is considered to be renewable energy. Currently in California there is a demand for renewable energy because the utility companies are required to meet the Renewable Portfolio Standard of 33% renewable energy in the electrical grid mix by 2020 (CEC, 2009). Additionally, in 2006 the state passed AB 32, or the Global Warming Solutions Act, which requires a reduction in greenhouse gas emissions to 1990 levels by 2020 (CARB, 2006). This bill creates a demand for clean energy and adds a premium for carbon neutral electricity. The rates paid for this renewable energy are discussed in detail in the economics section of Chapter 8 (Methods).

Emissions

Another important distinction between composting and anaerobic digestion is related to the emissions of VOCs and greenhouse gases (GHGs). VOCs are known to be a precursor to smog, can be toxic, and are often the source of odors. As discussed in the composting section, there are significant increases of VOCs when food waste is added to

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monitoring and odor control systems) from the biogas produced in the two digesters at the Elk River WWTP.

compost piles. Restrictions on VOC emissions from composting facilities would require the use of a cover and air filtration, greatly adding to the system cost. The anaerobic digestion system is an enclosed system and captures nearly all emissions (~98%) (US EPA, 2008a).

In terms of greenhouse gas emissions, both composting and anaerobic digestion reduce emissions when compared to landfilling. The main difference is that the composting process has been shown to generate both methane (CH_4) and nitrous oxide (N_2O). These gases represent two of the eight gases listed by the IPCC as greenhouse gases that need to be addressed in order to mitigate the impacts of climate change. A general schematic showing the sources of emissions from composting can be seen in Figure 5.1. For comparison, a general schematic showing emissions from anaerobic digestion can be seen in Figure 5.2.

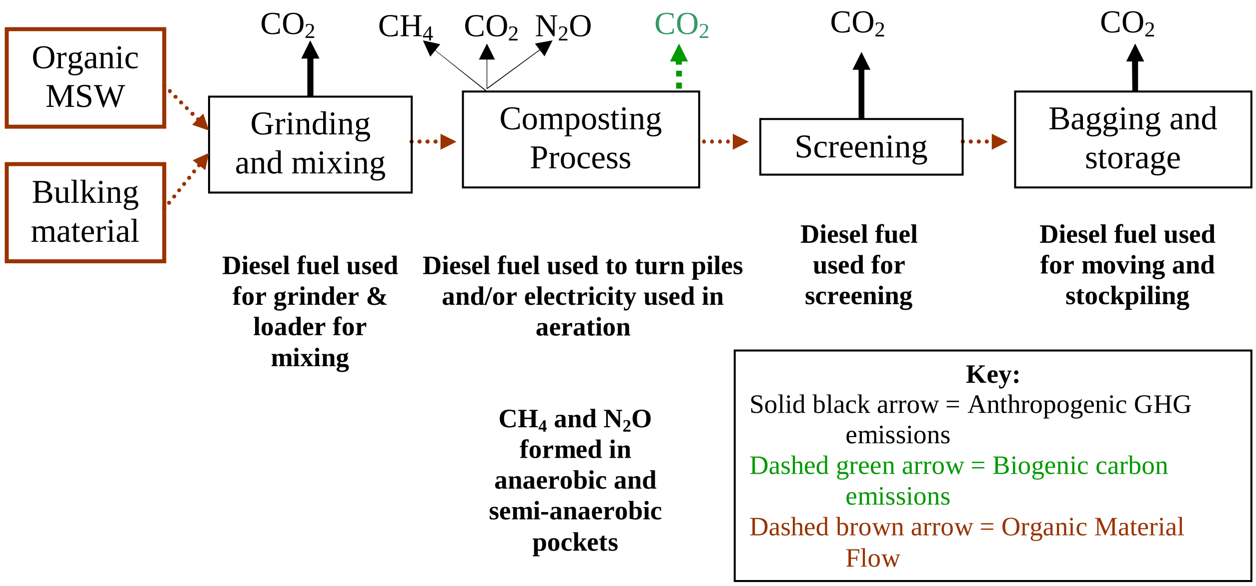

Figure 5.1 Sources of emissions from a typical composting operation. The wider arrows represent higher emissions levels. The green dashed arrows represent biogenic carbon emissions; these emissions are not considered greenhouse gas emission as they are a part of the atmospheric carbon cycle. It should be noted that in-vessel composting systems can reduce the emissions from the compost process itself by containing and filtering the air flowing through the piles.

Compost management practices such as frequently turning the piles, minimizing pile sizes, and covering the piles with finished compost can play a role in reducing the quantity of methane emissions released from composting operations. Increased turning frequency increases the levels of oxygen in the compost piles, reducing the number of anaerobic sites that can produce methane. However, increased turning requires energy inputs, releasing GHG emissions from the use of fossil fuels. Limiting the size of the compost pile can also be beneficial for maintaining aerobic conditions. This is because larger compost piles often develop more anaerobic zones that lead to the generation of CH_4 emissions (Fukomoto et al., 2003). Covering compost piles with finished compost, especially during the first few weeks of processing, helps to reduce emissions due to the active aerobic microbial populations present in the finished compost. The blanket of finished compost acts as a bio-filter where aerobic organisms destroy the volatile organic compounds escaping from material.[56]

Ultimately, what the literature review revealed is that some of the initial carbon and nitrogen in a compost pile will be emitted as methane and nitrous oxide regardless of turning frequency and pile size (Fukumoto et al., 2003; He et al., 2000; Hobson et al., 2005; Smet et al., 1999). Current research also suggests that fugitive methane and nitrous oxide emissions from composting may be small (2.5% of initial C, and 1.5% of initial N) (Brown et al., 2008). It should be noted, however, that the methane estimates are based on data collection at composting operations that did not process food waste. As methane and VOC emissions are directly related to the amount of initial carbon present in the waste stream, it may be beneficial to anaerobically digest wastes rich in volatile organic carbon (such as food wastes) before composting. After the waste passes through the anaerobic digestion process, the majority (>85%) of the initial volatile carbon will be converted to biogas while other nutrients will remain in the waste.

[56] Recent research shows conflicting results on which emissions are effectively removed through bio-filtration. The present state of the research suggests that volatile organic compounds can be removed, however, methane and nitrous oxide have been found (in some studies) to be unaffected by the bio-filter.

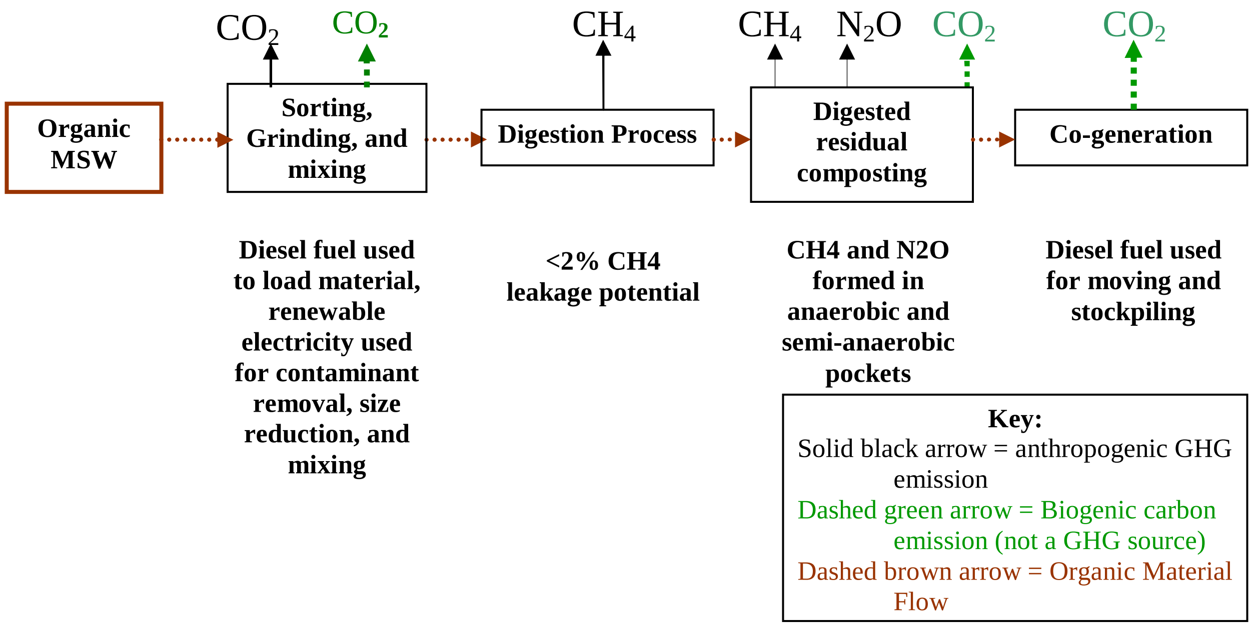

Figure 5.2 Sources of emissions from a typical anaerobic digestion operation. The wider arrows represent higher emissions levels. The green dashed arrows represent biogenic carbon emissions; these emissions are not considered greenhouse gas emission as they are a part of the atmospheric carbon cycle.

Emissions from anaerobic digestion mainly occur in the preprocessing and post processing stages. The pre-processing emissions can be limited as more electric equipment is used, as this power can be provided by the digester system and will not be considered a source of GHG emissions. There is a potential for N_2O and CH_4 to be produced from composting the residual digested material. Special consideration should be given to minimizing the emissions from the post digestion treatment of the waste.

Operational Parameters

The following bulleted list compares the required operational footprint and processing time for both in-vessel composting and anaerobic digestion.

- **Size of footprint required**: The composting process requires several stages that last four to eight weeks each. Because the processing, curing, and storage stages are longer for composting than the corresponding steps for anaerobic digestion, a larger area is required for the continual addition of incoming material. HWMA staff conducted a survey of California compost facilities that are permitted to accept food waste. Nearly all of the facilities surveyed used the turned windrow composting method. The average size of the facilities surveyed was 109 acres, and the average throughput of food waste was 370 tons per year (HWMA, 2007).[57] The large amount of land typically needed for municipal-scale composting dictates that most facilities purchase cheaper land far from population centers. In-vessel composting systems can process waste faster and therefore require less space. The average required acreage for in-vessel systems cited by the HWMA RFI respondents was four acres, often not including space for curing (HWMA, 2010). The required footprint for the anaerobic digestion of an equivalent quantity of food waste is estimated to be smaller (two acres) than the footprint needed for either composting method.[58] This footprint includes space for a receiving facility, digesters, and a solids drying area. The smaller footprint enables anaerobic digesters to be placed closer to population centers where the waste is

[57] It should be noted here that there was a large variation in the ratio of food waste to green waste processed at the facilities contacted. As such, the total footprint is not a reflection of the required area for food waste composting alone, but rather the required area for the green waste throughput that is the primary feedstock for most of the operations.
[58] In the case of 10,000 tons of organic waste per year, an estimated six acres would be needed for composting compared to two acres for anaerobic digestion.

generated, reducing the trucking necessary, as well as the carbon footprint of processing.

- **Processing time**: Depending on the process chosen, the complete composting process time is eight to 24 weeks whereas anaerobic digestion requires only three to seven weeks (the latter value assumes a three week aerobic curing phase), or one third of the time needed for composting.

In summation, the pairing of anaerobic digestion with residual composting optimizes the use of the energy content in food waste while reducing fugitive VOC and GHG emissions. As this approach has the potential to capture and utilize the energy generated from waste decomposition while still meeting US EPA pathogen reduction requirements and returning nutrients to the soil, the remainder of this study focuses on the feasibility of utilizing the anaerobic digestion process for food waste diversion in Humboldt County.

CHAPTER 6. FOOD WASTE DIGESTION IN NORTH AMERICA

There are over 70 operating digesters processing food waste in Europe today (De Baere, 2007). Currently in North America, there are only three projects processing municipal scale food waste, and four other projects that either process food waste on a pilot scale or are in the nascent stages of development. Although this technology is being widely adopted in Europe, the U.S. market has yet to be developed. The successful adoption in Europe is partially the result of a European Union ban on organics in landfills, as well as the high rates paid for renewable energy fed into the electricity grid (CIWMB, 2008). The following is a description of existing and developing food waste digestion facilities in North America. The first three projects process food waste at the full municipal scale, the latter four only process a portion of the food waste stream.

East Bay Municipal Utility District (EBMUD)

EBMUD, located in Oakland, California, is leading the food waste digestion effort in the U.S. Like other municipal agencies, EBMUD recognized the potential to turn organic waste into energy. The EBMUD project is located at the wastewater treatment plant (WWTP). This WWTP has extra digester capacity due to a shift in land use patterns; i.e., many large digesters were built when the city expected growth in the industrial sector producing large amounts of waste. However, over time, residential development flourished and the WWTP ended up with extra space in the digesters that was unneeded for industrial waste processing.

EBMUD sees this extra capacity as an opportunity to digest food waste and other organic residuals (Suto, 2008).

Partnered with the local waste hauler, Recology (formerly Nor Cal Waste Systems Inc.), EBMUD started to receive waste in 2004. The hauler is responsible for collecting and pre-processing the waste. Pre-processing includes contaminant removal via a trommel screen, a star grinder for initial size reduction, a magnet separator for ferrous metals removal, an air separator for plastics, and a hammer mill for final size reduction. The organic slurry is then delivered to a receiving pit at the WWTP for processing. The WWTP found that the waste still contained a grit that consisted of metals and shells. This grit caused processing problems as it clogged the outlet tubes from the holding tank and destroyed pumps going to the digester. For this reason EBMUD purchased a peristaltic pump[59] designed to handle abrasive materials and has developed a proprietary "Paddle Finisher" in order to further remove grit from the organics stream. The paddle finisher consists of two to four paddles that rotate along the inside of a cylindrical screen. The soft, organic materials are extruded through the small openings in the screen while the more fibrous and/or non-organic materials (~10% of the total solids) are rejected. The organic pulp is then pumped to the digesters, while the rejected material is hauled to the landfill (Gray et al., 2008).

The EBMUD facility is currently set up to accept 40 tons per day of food waste. The food waste is piped into six to seven digesters to be co-digested with the municipal wastewater solids. EBMUD is interested in digesting the food waste separately from the

[59] The usual application for peristaltic pumps is in the mining industry.

municipal sewage sludge and has been testing the digestibility of the food waste pulp via bench-scale digesters to determine the optimal operating parameters. Results from the study indicate that food waste pulp processed with their finishing technology is more biodegradable than wastewater solids and will leave less residual solids after digestion. Additionally, the EBMUD studies show that food waste pulp can be fed to the digesters at a higher loading rate than wastewater solids (0.6 lbs. VS/ft^3/day vs. 0.20 lbs. VS/ft^3/day) (Gray et al., 2008). These results indicate that food waste has a “lower concentration of toxic materials than municipal sludge” (Gray et al., 2008). When the gas production was compared to the standard gas production of wastewater solids the study showed that “approximately 3 to 3.5 times as much methane can be produced per unit digester volume from food waste pulp than from municipal wastewater solids” (Gray et al., 2008). This in conjunction with the higher loading rates and the increased digestibility means that smaller digester volumes can be utilized to process food waste – possibly resulting in lower capital costs.

The EBMUD project had to shut down its food waste digestion operations while the grit issue was resolved (Suto, 2008). As of this writing, they are operating again and processing 23 tons per day of food waste from the commercial sector. They are also processing blood, fats, oils, and grease and are currently working towards stand-alone food waste digestion utilizing the extra digester capacity available onsite (Suto, 2008).

The Toronto Dufferin Organics Processing Facility

The Dufferin Organics Processing facility is located in Toronto, Canada, and processes the city's residential organic waste. Opened in 2002 and operated by Canada Composting, the project collects source separated organic waste from 70,000 households participating in the city's "green bin" program. Since its inception, more cities have signed on to the Green Bin program and participation now stands at 510,000 single family households (Toronto, 2010). The waste is trucked to a pre-processing facility where it is visually inspected before it is loaded into a hydropulper for contaminant removal. The hydropulper is a patented technology that is essentially a blender in a washing machine. The blade chops up the waste and the organic material is extruded through the small holes in the sides of the drum. The contaminants are separated from the organic waste through a screening process, and are disposed of at the landfill. The pre-processing facility has an odor management system that consists of a bio-filter with finished compost as the filtration media. The organic pulp is loaded into the single-stage digester while the rejected contaminants are taken to the landfill. The stabilized residual solids are taken to a compost facility where they are converted into a soil amendment.

This project's success is due in large part to high levels of participation from the residential sector. This was achieved through a series of "open house public consultation events" held with the community members to ascertain what was important to them in order for them to be motivated to participate. The participant's two main concerns were the ability to put their organic waste in plastic bags and that all things "stinky" would be collected weekly. The result of these stipulations is a large quantity of plastic contamination in the diverted food waste stream. The hydropulper technology used at the facility is effective at removing the bags and therefore all organic waste including diapers can be put into the green bins. The City of Toronto developed a new waste collection system to accommodate the additional organic hauling routes and to keep costs low for the ratepayers. This system utilizes dual stream waste collection trucks to collect all things organic along with recycling one week, and all things organic and trash on the alternating week. The project manager reports a "greater than 90%" participation rate.

The Dufferin plant does not currently generate electricity with the methane produced from the digesters.[60] This was due to uncertainty about the quantity of gas that would be produced when the project was started. The City of Toronto is now expanding operations due to high participation rates and plans to build two new facilities complete with systems to co-generate heat and electricity. They also plan to add a cogeneration system at the existing Dufferin facility. Each facility will be capable of handling 55,000 metric tons / year, or 136 tons / day. These facilities are part of the city's plan to reach 70% diversion from landfills by 2010.[61]

Newmarket Digestion Plant

The Newmarket digestion plant, located just north of Toronto, was opened in 2004 and was then closed in 2006 due to odor complaints. The plant was then purchased from Canada Composting by Halton Recycling Limited. Halton Recycling immediately contacted an odor control specialist who now runs the plant. The specialist, Noel Moya,

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[60] The digester gas is currently flared.
[61] Personal interview with Dufferin organic waste digester plant manager November 2007.

found that the odor control system was under-sized. This design error included the blowers, the ducts and the bio-filters.[62] The plant was upgraded with a larger air-exchange system, new bio-filters that are backed up by five carbon filters, and quick-closing doors to keep odors inside the processing facility (Moya, 2008). The facility also uses the BTA hydropulper technology, but the operators have altered the equipment to more effectively handle diapers.[63]

The plant operator, Noel Moya, found that from his experiences the BTA equipment was expensive to operate and maintain. Mr. Moya also cautioned against allowing plastics in the source separated organic waste stream. Mr. Moya stated that, in his opinion, Toronto made a mistake allowing the stakeholders to use plastic bags and put diapers into the organic waste stream. The waste stream that the Newmarket plant receives has about 25% plastics and removing the plastics requires a lot of energy. He further stated that Germany, which leads Europe in municipal organic waste digestion, does not allow plastics in their source separated organics (SSO) waste stream and has no problems. “It is a political issue, not a practical issue” he stated. His advice is to prohibit the use of plastics from the start to avoid expensive pretreatment.

[62] Bio-filtration is the process of pulling foul air through wood chips or finished compost in order to remove odorous compounds.

[63] The fibrous materials in the diapers were found to be clogging the hydropulpers, so the blades on the main shaft were altered to chop up the fibers before they could sink.

The University of California (UC) Davis and Onsite Power Project

In October 2006, UC Davis and Onsite Power Systems Inc. unveiled their prototype high rate anaerobic digester system. Partially funded by the California Energy Commission, this digester system is a pilot scale plant capable of handling eight tons per day of organic waste. The waste streams utilized by this project include food waste, grass clippings and animal wastes. The system has not yet been run continuously and is not designed to handle a large municipal waste stream. The project model is high temperature (135°F) high rate digestion that can capture hydrogen as well as biogas.[64]

What is unique about the project is that it can handle solid waste with little pre-processing. The waste is loaded into the acidification or first stage digesters where it decomposes and produces water and organic acids. The "acid water" is then decanted off of the remaining solids and put into a second stage digester where the methanogenic organisms generate biogas. The two stage digestion system is designed to capitalize on the dissimilar metabolic rates of the bacteria (acid formers vs. methane formers) that break down organic waste in anaerobic conditions. The acid formers can exist in almost all conditions, and have a relatively fast metabolic rate. Conversely, the methane formers are sensitive to temperature and pH changes and have a slower metabolic rate. By separating the two phases, the digestion process can occur at a faster rate overall.

This project is still in the development stages and at the time of this writing has only begun to process waste on a regular basis. The benefits of this design are complete

[64] The information in this section comes from both visiting the UC Davis digester project, and multiple conversations with project developers Josh Rapport and Dr. Ruihong Zhang of UC Davis (2008).

pathogen destruction and the potential for hydrogen capture from the first stage. However, the capture of hydrogen in the first stage results in decreased methane formation in the second stage.

Chevron-Millbrae

Located in Millbrae, CA, this digester processes fats, oils, and grease. The city's waste water treatment plant receives 3000 – 6000 gallons of restaurant grease (or Fats Oils and Grease – FOG) daily and processes it in the existing anaerobic digesters. The grease and other organics are mixed with the municipal sludge and co-digested. The additional organics generate ~1.7 million kWh annually which meets 80% of the wastewater treatment plant's electrical load. The offset demand from the utility power grid will also avoid 1.2 million pounds of CO_2 emissions annually. The upgrades to accept the FOG and generate electricity via a 250 kW micro-turbine did not cost the wastewater treatment plant's ratepayers any money. The project paid for itself through the $0.10/gallon tipping fee paid by waste oil haulers, a rebate from the state of California's Self Generation Incentive Program, and the savings generated from the offset electricity demand at the waste water treatment plant. The FOG waste stream is seen as a huge potential source of renewable energy, and it also helps keep the sewer lines from clogging (Chung et al., 2007).

Inland Empire Utilities Agency (IEUA)

Another local plant processing some food waste is the IEUA. This plant co-digests manure, food waste, and FOG. The digesters were installed in 2006 and produce 400,000 – 600,000 ft^3/day of methane gas.[65] The digesters are operated at mesophilic temperatures with a 20 - 25 day solids retention time. The biogas is used to generate electricity, and the remaining digested solids are either land-applied or composted.

Sacramento Municipal Utility District (SMUD)

SMUD is involved in the development of two food waste digester projects. The first is a digester that will process the food waste generated at Folsom State Prison. The second digester will be sited adjacent to the Sacramento municipal wastewater treatment plant and will digest food waste in order to produce biogas for the purpose of augmenting the gas supply at that facility.

A feasibility study and a statement of interest solicitation have been completed for the Folsom project. The estimated quantity of food waste to be digested is 50 tons per day, most of which will be coming from the prison and the remainder from the community of Sacramento. The statement of interest solicitation resulted in responses from European vendors who indicated that they were interested in developing the project up to and including providing the financing. The project is currently on hold until Folsom State Prison decides how they want to move forward.[66]

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[65] Inland Empire webpage: http://www.ieua.org/facilities/solid.html, accessed June, 2008.
[66] Personal communication with project manager Ruth McDougal of SMUD June 2008.

In 2007, SMUD contracted with Brown and Caldwell to conduct a feasibility study for adding organics into their existing digester facility at the Sacramento Regional Wastewater Treatment Plant (SRWWTP). The biogas from the SRWWTP provides a small portion of the fuel at the adjacent Carson Energy Cogeneration Plant, which runs primarily on natural gas. SMUD commissioned this work to estimate the amount of renewable energy that could be generated with the addition of available organic waste streams (Brown & Caldwell, 2007).

A pilot test of a fats, oils, and grease digester was initiated on December 2, 2008. The project is digesting 5,000 to 7,000 gallons per day of FOG that is diverted from a rendering facility nearby. Once this pilot has been successfully established, the project team plans to move forward with liquid food waste, namely expired soft drinks. Following successful implementation of the first two stages, the third and fourth stages would include glycerin and finally food waste.

CHAPTER 7. DESCRIPTION OF PROPOSED HUMBOLDT COUNTY FOOD WASTE DIGESTER SYSTEM

HWMA proposes to develop a food waste digester facility to serve Humboldt County. The facility would be located in Eureka near existing waste hauling routes and population centers. This facility would receive and process post-consumer food waste, producing biogas and a valuable soil amendment. The biogas will be used to generate electricity and heat that will help to offset the costs of managing this waste stream. This facility will enable Humboldt County to reduce the environmental and economic impacts of waste management. This chapter provides a description of the proposed system. A flow diagram showing the main components of this system can be seen in Figure 7.1.

The food waste digester system proposed here begins with waste collection. Collection can either be accomplished through source separation and separate collection or though mechanical separation of mixed waste. The initial system will be sized to process source-separated commercial and industrial food waste.

The organic waste will then be hauled to the digester facility for pre-processing in order to prepare the organic material for digestion. Pre-processing consists of contaminant removal, grinding and/or chopping the waste, and may also include dilution. The pre-processing steps will occur in an enclosed building equipped with an odor control system.

After the pre-processing step, the waste is held in a homogenization, or buffer, tank until it is metered into the digester system. The digestion process produces biogas and a liquid/solid soil amendment. The biogas will be scrubbed and sent to a cogeneration engine to be converted into electricity and heat. The residual soil amendment can be converted into compost and a liquid fertilizer. These process steps are described in detail in the sections that follow.

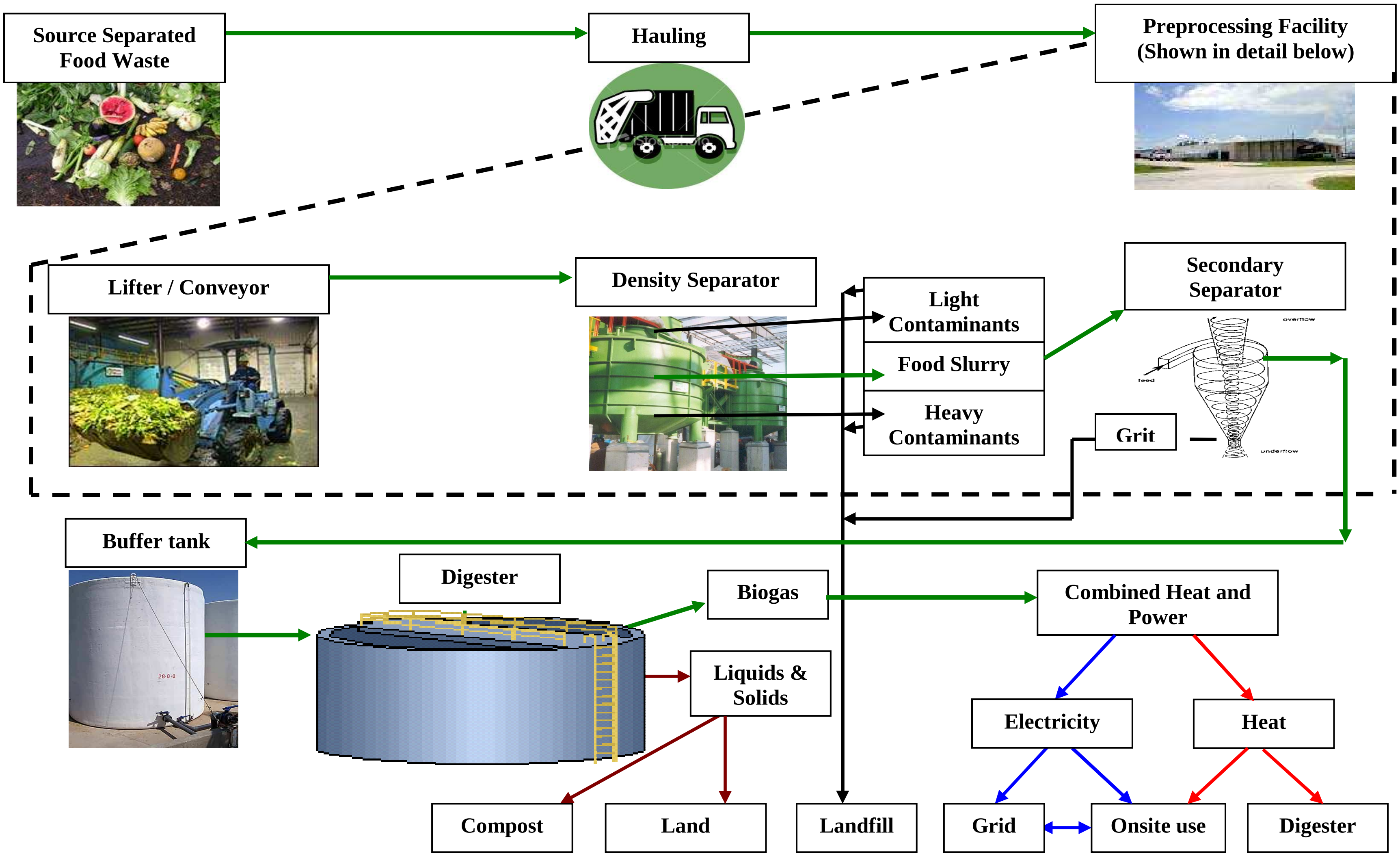

Figure 7.1 Process Flow Diagram for a food waste digester. Green arrows are organic material flow, the black arrows follow contaminant flows, and the brown, blue and red arrows show end products.

Collection

HWMA plans to initiate this digester facility by collecting from the commercial and industrial sectors. Plans for phase two of the food waste diversion program will include residential food waste. Residential and commercial food waste collection programs are already operating in many California cities. According to a report commissioned by the US EPA Region 9[67] on the status of organics recycling programs in North America, there are 40 established residential organic waste collection programs in California (CCWI, 2010). There are an additional 26 food waste collection programs in other states and 55 in Canada (CCWI, 2010). According to the study, six of the 40 California residential organics collection programs surveyed collect food waste separately from green waste and 19 out of 40 collect separated food waste combined with yard trimmings (CCWI, 2010). Three cities have banned food waste from the disposed waste stream, and the majority of the programs surveyed collect the organic waste weekly with a separate collection route (CCWI, 2010). This report confirms that communities in California are finding success with organic waste collection programs, and that there exist working models to draw from when designing a collection system.

Collecting a source separated organic waste stream can result in low contamination levels. This can be accomplished through mandatory or voluntary organic waste collection programs. The mandatory programs are able to achieve 90%

[67] EPA Region 9 serves Arizona, California, Hawaii, Nevada and the Pacific Islands.

participation whereas the voluntary programs achieve 17-40% participation (CCWI, 2010).

Collection programs typically consist of kitchen bins for daily food scrap collection, then a larger container (30-65 gallons) for curbside collection (CCWI, 2010). A “motivated and engaged citizenry” was cited as the underlying factor for the success of the programs surveyed. Problems cited in the survey are odors, contamination, and low voluntary participation rates (CCWI, 2010).

Hauling

Hauling food waste will require the use of rear-loading garbage trucks, large flat-bed trucks, and pumper trucks. Participating jurisdictions will be responsible for developing contracts with waste haulers for local food waste collection. FOG and other liquid wastes such as cheese whey or manure slurry, will be hauled using pumper trucks. Once the trucks arrive at the organics processing facility, they will cross over an automated weighing scale that records the tonnage received, and identifies the hauler. The haulers will then proceed to the processing building where they will back in and dump the food waste onto either a recessed cement floor or a receiving pit. Liquid wastes will be pumped directly into a separate receiving tank. A computer and card reader system will record where the trucks are coming from, and how much waste they are depositing. This will enable tracking of participation, diversion and greenhouse gas reductions.

Pre-processing

Pre-processing involves contaminant removal and size reduction and is one of the most challenging parts of food waste processing. Removing non-organic contaminants like silverware and plastics from food waste is difficult due to the density and high moisture content characteristics of the waste. There are many configurations of pre-processing equipment in use today. Pretreatment equipment needs are based on the condition of the waste as well as the type of digester process chosen. The following sequence describes the pre-processing equipment currently used in operational food waste digester systems. Some of these steps may not be necessary depending on the digester system chosen (see section 0). These treatment trains can include but are not limited to visual inspection, screening, magnets, grinders, density separators, and paddle finishers.

- **Visual inspection**: The digester facility staff will visually inspect the incoming waste to identify highly contaminated loads. If a load of source-separated waste is too contaminated, it will be rejected. A condition of accepting waste will be based on maximum allowable level of contamination. This policy will help to maintain low contamination levels in order to reduce the time and energy required for pre-processing. Load inspections can be used to identify the origin of the highly contaminated waste so that the waste generator can be contacted and measures can be taken to improve the collection efficacy.

- **Screening:** Trommel screens can be used to separate larger contaminants from food waste. Trommel screens are rotating drums with pore sizes that are selected to separate one size of material from another. The objects smaller than the pore size selected fall through the screen, while the larger objects remain in the drum. Multiple screen pore sizes can be utilized depending on the material being screened.

  Another type of screening technology is the paddle finisher. Paddle finishers are common in food production for use in pulping, juicing, and oil separation. Similar to the trommel, paddle finishers also use a horizontal drum screen. In contrast to the trommel, the paddle finisher screen pore size is significantly finer, and the drum does not rotate. Instead, a set of "paddles" pushes food waste materials through a fine screen, separating out and trapping large contaminants while extruding a fine pulp on the exterior of the drum. A paddle finisher is used at the end of a pre-treatment process train to remove any smaller-sized contaminants and grit that remains in the waste.
- **Magnetic separators**: A magnet, or set of magnets, is placed on the end of a conveyor belt or grinder to remove ferrous metals (steel silverware).

- **Grinders**: Grinders chop the material into a homogenous size. This is essential for maximizing the surface area available for microbial decomposition. Grinders are widely used at composting facilities and wastewater treatment plants. Grinders in food waste digester projects have to handle metals and plastics as these contaminants are commonly found in source separated organics. Coarse and fine grinders may be used in separate pre-processing steps to condition the waste for subsequent steps.

- **Density separators**: Density separators use centrifugal force and water to separate contaminants from the food waste in a large tank. Heavier contaminants sink to the bottom of the tank, while lighter contaminants float on the top, leaving the processed food waste slurry to continue through the process. Hydropulping is an example of density separation technology. In a hydropulping cycle, food waste is added to a tank and mixed with water. An agitator spins the food waste slurry at a high velocity. The hydropulper uses hydraulic shear to de-fiber the food waste into a homogenous pulp (JG Press, 2005). In addition to pulping, the cyclonic action causes most of the lighter contaminants such as plastics float to the top of the tank where they are periodically raked off. Heavier materials such as glass, coins, silverware and grit are pushed to the bottom of the tank where they are collected in a trap and removed. The organic slurry is extruded through the small holes in the drum where it then passes through a finishing separator to remove any remaining grit.

- **Processing:** Once the contaminants have been removed, the material is homogenous and is ready for digestion. There are two main anaerobic digestion pathways: co-digesting the food waste with municipal sewage

> sludge and stand-alone digestion of food waste.[68] The main difference between the two processes is the quality of the residual solids. Municipal sludge can contain heavy metals, pharmaceuticals and other chemicals due to uncontrolled dumping down drains. The US EPA has established regulations (US EPA Part 503 Rule) regarding the post-processing heat treatment and safe end uses of these solids. However, public opposition to the local spreading of sewage solids is a barrier to the widespread use of these solids as fertilizers. The treated solids from wastewater treatment facilities are usually landfilled or land applied.[69] Land application is increasingly more difficult as water quality regulations become more stringent. Many communities do not allow these residuals to be applied to their land for concern that that toxic substances will get into their water supply.

Due to the challenges associated with disposing sewage sludge, HWMA has chosen the path of stand-alone digestion. Stand-alone digestion requires a higher initial capital outlay, but produces a cleaner residual. This residual can be can be composted with green waste or land applied, and has a market value that can generate an additional revenue stream.

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[68] Stand alone digestion can include other clean organic wastes such as manure, yard waste and industrial organic waste products.

[69] The Eureka wastewater treatment plant is currently land-applying their solids. Due to the agronomic restrictions on nitrogen accumulation in soils as well as water quality concerns, the wastewater treatment operators are looking for new land where the treated solids can be applied.

Main Components of an Anaerobic Digestion System

There are many variations of digester systems used for processing organic waste. HWMA has not yet selected a specific technology, so the following is a general description of the system components for a wet (<15% solids) digestion system. If a dry digestion system (>15% solids) is chosen, less water will be added to the system, pumps may be replaced with screw augers (for loading the digester), and some pre-processing and mixing may not be necessary.

A general mass flow balance for anaerobic digestion of food waste is shown in Figure 7.2. The following assumptions apply to this mass-flow diagram: 30% total solids content (TS), 87% volatile solids (VS/TS), 80% VS destruction, and process water re-use. This mass-flow balance does not show the addition of water for dilution.

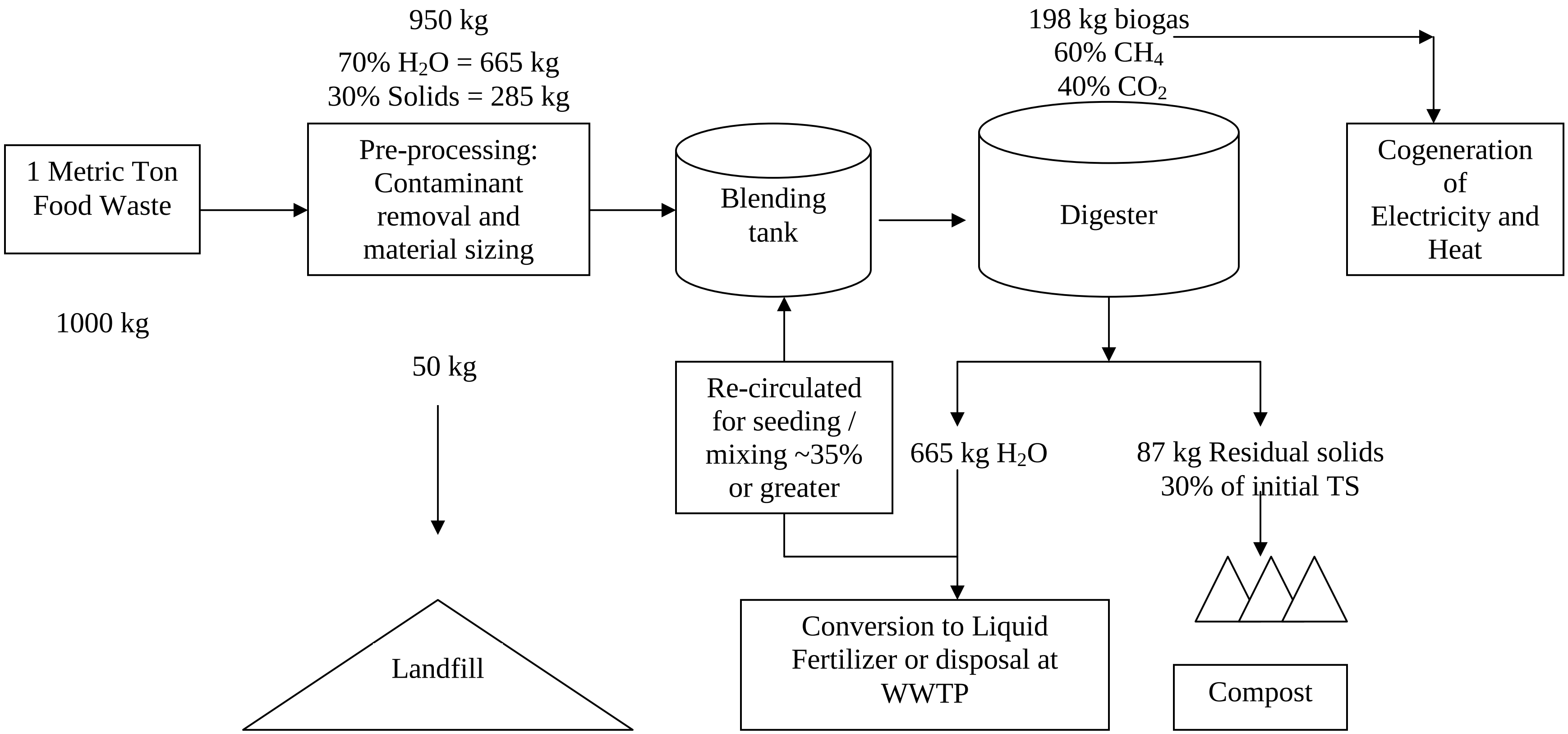

Figure 7.2 A general mass-flow balance for an anaerobic digestion system.

The following is a list of the major components of an anaerobic digestion system:

- **Homogenization tank**: Also called a “buffer” tank in this analysis, this is a tank that will hold the slurried organic material until it is fed into the main digester. This tank can be heated and can have mechanical mixing systems for keeping the material from stratifying.

- **Pumps**: Pumps are usually controlled by a computer system that loads the material into, and removes material from, the digester. These pumps operate at regular intervals throughout the day. Digested material is removed before the new material is put in. Like those used in mining and food processing applications, these pumps need to be robust enough to handle gritty wastes.

- **Digester tank:** Digester tanks are air-tight vessels that are central to the digestion process. Digester tanks are often lined steel tanks with a floating lid to allow the active tank volume to increase or decrease as biogas is generated. Digester tank volume depends on the feedstock specific loading rate,[70] the daily flow of waste material, and the desired hydraulic or solids retention time. Digester designs often include an additional 15% of volume, or head space, to have room for the biogas that is produced. There is 15% extra volume for the digester gas. The digester tanks are heated and mixed to ensure

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[70] The feedstock loading rate refers to the rate at which the methanogenic organisms are able to convert the volatile fatty acids produced by the acid forming bacteria. This is expressed as maximum throughput (kg VS or lbs. VS) per volume of digester space (m^3 or ft^3) per day

a rapid breakdown of material. The incoming waste is also pre-heated so as not to disrupt microbial activity.

- **Heating:** The slurried material and the digester can be heated with the heat from a cogeneration system or a boiler. A cogeneration system typically refers to an internal combustion engine (although it can also refer to a high-temperature fuel cell) with a water jacket that captures the heat from combustion. This heat can then be used in conjunction with a heat exchanger to heat the incoming sludge and the digesters themselves.[71]

- **Mixing:** Mixing the contents of the digesters ensures that the microorganisms have the most exposure to the organic material. Like heating, mixing maximizes the efficiency of decomposition. Mixing systems can be either mechanical (like a blender), pneumatic (compressed biogas injected into the lower part of the digester), hydraulic (injecting heated slurry into the bottom of the digester to create thermal, or convective, movement) or passively by using the natural cycles of gravity and gas evolution.[72]

[71] Currently, the digesters at the Eureka wastewater treatment plant are heated using the heat captured from the two internal combustion engines generating electricity onsite.
[72] For example, the Eureka wastewater treatment plant currently uses pneumatic mixing and the Arcata plant uses the hydraulic method.

- **Gas collection:** A gas collection system consists of pipes located at the top of the digester that transport the gas from the digester to the gas scrubbing and cogeneration systems.

- **Gas treatment:** Before entering the cogeneration equipment, the biogas is scrubbed to remove hydrogen sulfide and water. Hydrogen sulfide combined with water forms sulfuric acid, which over time damages electricity generation equipment. Iron exchange chemistry is a proven technology that has been utilized by the landfill gas industry for many years to remove hydrogen sulfide from biogas. When the iron exchange media is spent, it is non-hazardous, and can be disposed of in a normal landfill.

End products

The end products from a food waste digester are biogas, process water (digestate) and residual digested solids.

- **Biogas**: The biogas can be combusted to produce electricity and heat, compressed to be used as a vehicle fuel, or purified and injected into a natural gas pipeline. For this analysis, I have chosen cogeneration, or the generation of both heat and electricity, as the end use for the biogas. The reason behind this choice is the potential for the facility to be sited adjacent to the Eureka wastewater treatment plant (WWTP). The Eureka WWTP currently has a demand for the electricity and the heat on site, and more importantly, has a cogeneration system as well as an interconnection agreement with PG&E

already in place. By tying the gas from the food waste project in with the existing cogeneration system, significant capital investment costs can be avoided and the wastewater treatment plant can generate more electricity to serve the WWTP onsite loads.[73] In this analysis I have assumed that the cogeneration engine will achieve a 35% electrical efficiency.[74] Other technologies that can be used to generate electricity from biogas are fuel cells and micro-turbines.

- **Water**: The remaining process water (digestate) is nutrient-rich and can be used as a soil amendment. Digestate has been utilized for road medians and parks, as well as schools and farms. This process water can also be re-used in the digestion pre-processing steps and/or put into the WWTP head works for disposal.

- **Residual Digester Solids**: The residual solids from a stand-alone food waste digester are a valuable soil amendment. Ideally, these solids would be co-composted with green waste to form a nutrient-rich additive. The resulting humic material would be completely stabilized (i.e., have no remaining volatile components or pathogens), and can provide an additional source of revenue to the facility.

[73] The Eureka WWTP is currently undergoing a facility upgrade which includes the purchase of new cogeneration engines. The engineering firm developing the upgrade plan has stated that the new WWTP cogeneration equipment can be sized for both the biogas stream from the existing WWTP digesters as well as the biogas stream from the food waste digester project.

[74] The 35% electrical efficiency value is cited by bio-gas fired co-generation engine vendors (Martin 2009, Vernon 2010)

Footprint

The proposed Humboldt Regional Food Waste Digester Facility footprint will be approximately 2 acres. Included in this footprint is the access road, truck weighing scale, pre-processing building, tanks, and gas treatment equipment. Required tanks include the homogenization tank, FOG receiving tank, and two tanks for digestion (one for primary digestion and one for gravity separation and/or redundancy).

Site

A strong candidate for the food waste digester facility is a parcel of land adjacent to the Eureka Elk River WWTP (Figure 7.3) known as the Crowley property (Figure 7.4). This site is ideal because it is owned by the City of Eureka and is adjacent to the WWTP. The proximity to the WWTP facilitates the interconnection with the existing cogeneration engines, safety flare, and electricity loads. Half of the Crowley property is already being used for fire department training, while the other half, which is closer to the treatment plant, is available for other uses. This site is currently zoned as coastal-industrial. A road adjacent to the site can be used to access the facility. Part of the property is wetlands, and therefore a wetlands delineation study will be required prior to the digester facility's development.

Figure 7.3 The yellow rectangle shows the Elk River WWTP on the Humboldt Bay.
Source: Google Earth accessed August 2008.

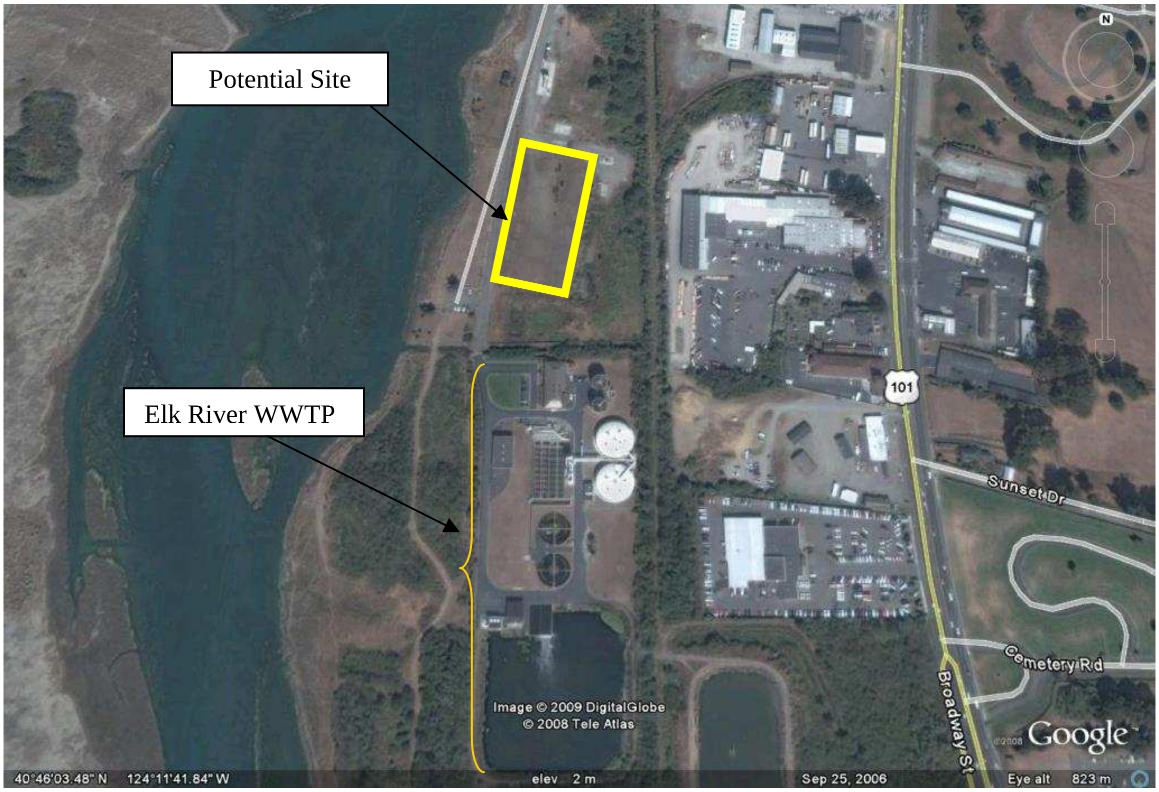

Figure 7.4 This map shows the potential project site known as the Crowley property. The Crowley property lies to the North of the Eureka Elk River WWTP. Accessed via Google Earth August 2008.

Permit Requirements

HWMA is currently working through the permitting process beginning with the California Environmental Quality Act (CEQA) Initial Study process. The initial study process is a permitting pathway whereby a lead agency formalizes a proposed project idea in order to determine whether an Environmental Impact Report (EIR) or Negative Declaration of impact must be prepared. This document includes a list of all potential impacts to the environment and surrounding community, and it also proposes mitigation measures to negate or reduce the impacts. This document additionally identifies the permits that will be required. Supporting studies that may be needed to complete an Initial Study are: biological assays, archaeological assays, and traffic studies. Once completed, the initial study will be distributed to all pertinent regulatory agencies for a 30 day comment period. Once the regulatory concerns have been sufficiently addressed, the document is made available for public comment. At the conclusion of both review processes, the lead agency can determine that 1) the project should be abandoned or moved to another site, 2) an EIR will be needed (extending the permitting time and cost), or 3) a Mitigated Negative Declaration of impact is appropriate (project development can proceed). The following permits and impact reports need to be obtained before the HWMA project can begin:[75]

- **City of Eureka –** Design Review Permit, Grading Permit, Building Permit, Coastal Development Permit, Rezone, LCP Amendment, Design Review;

- **Humboldt County Public Health Department –** Solid Waste Facility (SWF) Permit;

- **North Coast Unified Air Quality Management District (NCUAQMD) –** Permit for Internal Combustion Engines;

- **North Coast Regional Water Quality Control Board (NCRWQCB) –** National Pollutant Discharge Elimination System (NPDES) Storm Water, 401 Water Quality Certification, Waste Discharge & Biosolids Permits;

[75] The list of required permits was generated as part of the HWMA CEQA Initial Study document currently under development. HWMA has contracted a local planning firm, Plan West Partners, and sub-contractor, Ourevolution Energy & Engineering, to assist in this effort. This study was made possible with the help of an EPA Region 9 Solid Waste Assistance Grant.

- **California Department of Resources Recycling and Recovery – (CalRecycle)** Solid Waste Facility (SWF) Permit;
- **California Coastal Commission –** Coastal Development Permit Appeal Authority;
- **California Department of Fish and Game (DFG) –** Biological Review; and
- **U.S. Army Corps of Engineers (USACE) –** 404 Wetlands fill Permit.

Currently there are no defined regulations for food waste digester projects. This is due to the dearth of existing food waste AD systems in North America. An additional objective of developing the HWMA Initial Study is to expose the regulatory agencies to the potential benefits and characteristics of food waste digester facilities. Concurrent with this effort, the California Department of Resources Recycling and Recovery has commissioned a programmatic EIR for food waste digesters. Both efforts should result in a more clearly-defined regulatory structure that can potentially streamline the permitting process in the future.

In addition to pursuing and funding the programmatic EIR, CalRecycle itself recently passed new directives that will affect the regulatory status of anaerobic digestion projects. Strategic Directive 6.1 sets a goal of 50% diversion of organics from landfills by the year 2020 (CIWMB, 2007b). To meet this directive, CalRecycle estimates that the organics processing infrastructure will need to expand by an additional 15,000,000 tons per year state-wide. Directive 8.5 mandates the CalRecycle staff to work with local jurisdictions to develop this infrastructure, which includes a regulatory framework for the implementation of organic waste conversion facilities. Directive 8.4 requires CalRecycle to ensure that all regulations reflect the current state of scientific knowledge and are in line with the goals of AB 32. A regional food waste digester in Humboldt County will help member jurisdictions and CalRecycle to comply with these new directives.

CHAPTER 8. METHODS

This feasibility study involved gathering information on the quantity of food waste in the Humboldt County waste stream, food waste digester biogas production rates, and the cost of developing a food waste digester facility compared to the cost of other food waste management strategies. Other metrics that were quantified include the projected greenhouse gas reductions associated with this project and the savings associated with offset waste hauling. The sections that follow describe the methodology that I used to determine this project's feasibility, life cycle cost, and environmental benefits.

Quantity of organic waste

The feasibility of any waste to energy project begins with an assessment of the waste resource itself. Estimates of the food waste diversion potential in the region were derived from local, state, and national waste characterization studies. The quantities of other organic waste streams were obtained directly from the source. The following is a description of the studies consulted and the resulting estimates used in the analysis.

8.1.1 Food Waste Resource

Local data were obtained from the 1990 waste characterization study performed to develop the Source Reduction and Recycling Element (SRRE) for Humboldt County (1992). This document was developed in compliance with the Integrated Waste

Management Act of 1989 (CA AB 939).[76] AB 939 mandated that all California jurisdictions divert 50% of their waste stream away from the landfills by the year 2000. I used these data as the baseline for estimating the amount of food waste in the residential and commercial waste streams. As these data are nearly 20 years old, I incorporated other regional waste characterization data (Table 2.1) to verify the quantities estimated.

In addition to the County-wide waste characterization study, annual food waste disposal rates were acquired from the California Department of Resources Recycling and Recovery's waste stream profiles. These profiles are based on 2004[77] and 2008[78] waste characterization studies. These data are based on waste sampling over four seasons, and across five regions in California. A total of 530 samples from 22 randomly selected waste disposal facilities were sorted in each of the studies. CalRecycle derived waste stream profiles for every jurisdiction in California using these data. The CalRecycle waste stream profiles for Humboldt County indicate that food waste is 20% of the disposed waste in the residential sector and 17% of the disposed waste in the business sector.

Other sources of food waste disposal rates that were factored into the available food waste estimate include waste characterization studies from nearby cities such as Portland and Alameda and the US EPA estimate of food waste in the national waste

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[76] In 1989 the Integrated Waste Management Act established both the California Integrated Waste Management Board (CIWMB) and the 50% state-wide waste diversion goals. In response to this legislation, Humboldt County hired Gainer and Associates to perform a waste characterization and waste diversion plan for Humboldt County.

[77] In 2004 CIWMB hired Cascadia Consulting Group Inc. to characterize the waste stream components across sectors (residential, commercial and industrial) and at all scales - cities, counties and state wide. Data can be found at: http://www.ciwmb.ca.gov/Publications/LocalAsst/34004005.pdf

[78] The 2008 waste characterization study can be accessed at: http://www.calrecycle.ca.gov/WasteChar/WasteStudies.htm#2008Study.

stream. The expected quantity of food waste in the commercial waste stream was taken from averaging these numbers. See Table 2.1 in Chapter 2 for the complete list of waste characterization studies and data that were used to calculate the percent of food waste in the commercial waste stream.

The following list describes the waste characterizations used in quantifying the food waste tonnage available for processing:

- The US EPA: Municipal solid Waste in the United States: 2007 Facts and Figures. This report is the most recent in a series of reports sponsored by the U.S. Environmental Protection Agency to characterize municipal solid waste (MSW) in the United States. Together with the previous reports, this report provides a historical database for a 47-year characterization (by weight) of the materials and products in MSW (US EPA, 2007). Because this is a nation-wide analysis, the data were derived using a “materials flow methodology” rather than direct sampling. The materials flow methodology is based on production data that are adjusted for imports and exports. For food and other organic wastes, sampling data from across the nation were used in conjunction with the production data. Due to the national scale of this analysis, these data come with the caveat that local waste stream characterizations should be performed to obtain a more accurate description of the waste stream. These data should only be used as a “ballpark figure,” as regional variations in population density, commercial and industrial activity and local waste management practices will significantly change the nature of the waste stream. The US EPA estimate was included in the calculation as a low-end value.

- Alameda County Waste Management: (http://stopwaste.org/). In 2000 and 2005 the County of Alameda hired RW Beck to perform waste characterizations throughout Alameda County. These studies were commissioned in response to the changing nature of the waste stream after recycling and green waste programs were implemented in response to AB939. The characterizations involved 1,060 hand-sorted samples as well as 739 visually sorted samples.[79] As evidenced in Table 2.1, the percent food waste in the waste stream increases relative to the diversion of other components of the waste stream. The higher value of 26.1% was not used to estimate the Humboldt County value as it reflects a very aggressive waste diversion program.

- Oregon Department of Environmental Quality: Oregon Solid Waste Characterization and Composition 2005/2006. Waste characterizations are done regularly in Oregon as required by state law. The characterizations are done through sampling and then adjusting for cross contamination (such as food waste left in a plastic container). This study found food waste to be 15.7% of the overall waste stream. The Oregon study includes a comparison of the 2005/2006 data to the 2002 data. Marion County, Oregon chose to pay for additional sampling in the County in order to get a more refined waste characterization. The Oregon DEQ

[79] Visual sorting is a method in which a sample is not physically sorted, but is visually evaluated for broad category constituents such as paper, metals, glass etc.

report compares the data from Marion County to the statewide characterization. The Marion County data reveal the importance of performing local characterizations. This can be seen in the difference (larger % food waste in total waste stream) between the County and State-wide characterizations.

Using the aforementioned waste characterization studies, the quantity of food waste in the Humboldt County commercial waste stream was estimated to be 18%. This percentage was then applied to the recorded tonnage of commercial waste disposed at the HWMA transfer station from each of the member cities of Humboldt County. An example of this calculation is as follows:

$$\text{Tons MSW}_{\text{CMRCL}}/\text{Yr} \times \%\ \text{Food Waste}_{\text{CMRCL}} = \text{Tons Food Waste/Yr}_{\text{CMRCL}}$$

8.1.2 Other organic waste streams:

Food waste is but one of several organic waste streams available for conversion to energy. In every community, there is grease trap waste, meat scrap waste, and (potentially) food processing waste. All organic waste streams should be examined when considering an organic waste digester in order to maximize revenues associated with the project. For this initial feasibility study, Footprint Recycling, a grease trap waste hauler, and Cypress Grove, a goat cheese manufacturer, were contacted to obtain information on the quantity and nature of this organic waste stream. Further work will be needed to identify the remaining sources of organic waste that could benefit from local processing.

Approximate gas production potential

Biogas production values from existing organic waste digester projects in Europe and North America provided a range of gas production rates that could be used to estimate the annual renewable energy potential from this project. Table 8.1 shows the ranges of gas production values reported from these projects as well as the values from organic waste digestion research.

I estimated the annual biogas generation potential from Humboldt County's food waste stream by taking the average of the gas generation values listed in Table 8.1 and applying it to the expected food waste tonnage. The calculation is as follows:

$$\text{Tons food waste/year} * \text{ft}^3 \text{ biogas/Ton food waste} = \text{ft}^3 \text{ biogas/year}$$

Table 8.1 Reported biogas production from food waste digestion

Biogas Production Factor		
m^3/ Metric ton	ft^3/ US short ton	Source:
150	4,806	Dry digestion process: DeBaere, L. (2000)
150	4,806	Valorga Process:Lissens, G. et al. (2001)
160	5,126	Valorga process: Nichols, C. E. (2004)
100	3,204	Waasa process: Nichols, C. E. (2004)
150	4,806	Waasa process: Nichols, C. E. (2004)
130	4,165	Kompogas process: Nichols, C. E. (2004)
100	3,204	Dranco process: Nichols, C. E. (2004)
200	6,407	Dranco process: Nichols, C. E. (2004)
113	3,620	Haight, M. (2005)
110	3,524	Dufferin Organics Processing Facility: Goldstein, N. (2005)
120	3,844	Dufferin Organics Processing Facility: Opstal, B.V. (2006)
165	5,286	Zhang, R. et al. (2007)
113	3,620	Kelleher, M. (2007)
144	4,613	BTA System, (2007)
103	3,300	Paul Suto, East Bay MUD (2007)
135	4,325	EBMUD: Gray, D.M.D., Suto, P. (2008)
134	3,915	Average gas production value

Gas production rates for the other organic waste streams investigated are reported in units of liters / gram volatile solids added (L/g VS). These values were generated through experimental analysis as reported by the sources listed in Table 8.2. Daily VS quantities are obtained by multiplying the tonnage of a given substrate by its % total solids (TS) content (i.e., solids that remain once the water is removed) and then multiplying that value by the %VS content of the TS. The reported values can be seen in Table 8.2.

Table 8.2 Gas generation rates for other organic waste streams in the Humboldt Bay area

Waste Resource:	TS %	MC %	VS % of TS	Total VS %	Biogas yield (L/g VS)	Source:
Fats, oils, & grease	29%	71%	95%	28%	1.42	Zhang wt al. (2007b)
Glycerin	88%	12%	92%	81%	0.673	Zhang et al. (2007a)
Whey	42%	58%	72%	30%	0.28	Ghaly, A. E. (1996)
Manure	13%	87%	80%	10%	0.194	Zhang et al. (2007a)

The annual gas production from these waste streams was calculated as follows:

$$\frac{\text{L}}{\text{g VS added}} * \frac{1\,\text{m}^3}{1000\text{L}} * \frac{1000\text{g}}{1\text{kg}} * \frac{1000\text{kg}}{\text{Metric ton}} * \left(\frac{\text{Metric tons}}{\text{Year}} * \%\ \text{VS in waste stream} \right) = \frac{\text{m}^3\ \text{biogas}}{\text{year}}$$

Digester tank sizing:

Digester tank sizing is based on the organic loading rate (OLR) that corresponds to the rate at which a stable microbial population can metabolize the feedstock. The digesters will primarily be digesting food waste, and as such, the average OLR found in the literature is used for all substances. The actual loading rate will depend on the ultimate mixture of organic waste resources available for digestion in Humboldt County. The OLR differs by substrate as each unique substance contains a varying level of readily digestible VS, as well as a corresponding VS destruction rate. For example, the food waste VS destruction rate is approximately 80% whereas the grease trap waste and glycerin VS destruction rates are closer to 99%. Once the mix of readily available organic waste resources has been determined, bench scale testing should be used to determine maximum loading rates for a completely mixed organic waste stream. Organic loading rates for anaerobically digesting food waste can be seen in Table 8.3.

Table 8.3 Organic loading rates for digesting food waste

Organic Loading Rates (OLR)		
lbs VS /ft^3/day	kg VS/m^3/day	Source:
0.60	9.6	Gray/Suto (2008)[80]
0.14	2.2	Brown and Caldwell (2007)
0.20	3.2	Brown and Caldwell (2007)
0.21	3.3	Dufferin Plant: Opstal (2006)
0.25	4.0	Dufferin Plant Operator (2007)
0.26	4.2	Typical SSO Processing: Opstal (2006)
0.28	4.43	Average OLR[81]

Digester sizing is calculated as follows:

$$\frac{\text{kg VS}}{\text{day}} * \frac{m^3 * \text{day}}{\text{kg VS}} = m^3 \text{ digester volume needed}$$

[80] The EBMUD loading rate listed here is higher than the others because this loading rate is the result of bench-scale testing to determine the highest loading rate that could be sustained given the high decomposability of food waste in digesters.

[81] As food waste digestion is a relatively new process, operators are only beginning to determine the maximum loading rates that can be sustained. For this reason, the EBMUD higher value is included in the average. For comparison, the median loading rate is 0.23 lbs VS / ft^3 / day (or, 3.65 kg VS / m^3 / day), which suggests that the average loading rate used to size the system was influenced by the higher value. As the actual size of the digester will also depend on other process specifications such as a dry or wet system (which have very different volume requirements due to the amount of water added to the system) this average value is seen to be appropriate for the purpose of the economic analysis.

An additional 15% of headspace for gas storage is then added to calculate the total digester volume needed. The digester volumes selected for the economic analysis are directly related to the expected quantities and VS content of the different waste streams collected and is based on a 20 to 25 day hydraulic retention time.

Electricity generation potential

I calculated the electricity generation potential by multiplying the annual biogas generation (m^3/year) by the energy content of biogas (MJ/m^3). Energy content values from the literature can be seen in Table 8.4. The energy content in biogas is directly tied to the percent methane content in the biogas mixture. Methane content is dependent on the substrates digested as well as the process operating parameters chosen. In general, biogas generated from anaerobic digesters is comprised of 60% methane and 40% carbon dioxide. This results in an energy content of approximately 600 BTU/ft^3.[82] The gross electrical energy can be calculated by converting the energy contained in the biogas mixture into electrical energy units (1MJ = 0.278 kWh). The biogas can be converted to electrical energy via an internal combustion engine, turbine, or a high temperature fuel cell. Each of these technologies has a conversion efficiency associated with converting the biogas to electricity. In order to calculate the net electrical and thermal energy potential, a conversion efficiency percentage can be applied to the gross energy content in the biogas. For this analysis, I chose an internal combustion co-generation engine as two such engines are already in use at the Eureka WWTP. Although these engines are quite

[82] This energy content reflects the Higher Heating Value for biogas.

old, the treatment plant is currently undergoing a systems upgrade, which includes the purchase of new cogeneration equipment. It is assumed that the gas from the food waste project will be utilized in these same engine generators. Based on conversations with Martin Machinery and GE Jenbacher, distributors for engines fueled with biogas, the expectation is that 35% of the biogas energy will be converted to electricity and an additional 30% of the energy will be captured and used as heat. As a result, the combined efficiency of the co-generation system is assumed to be 65% (Martin, 2009).

Table 8.4 Energy content of biogas

Calorific value of biogas		
MJ/Nm^3	MJ/ft^3	Source:
19 to 26	0.54 to 0.74	MOP11 (1976)
20	0.57	Hessami et al. (1996)
16 to 22	0.45 to 0.62	IPCC (2007)

Once the net electrical energy generation has been calculated, the total quantity of useful energy must be adjusted to account for the “parasitic load.” The parasitic load is the amount of energy needed to run the grinders, pumps, mixers, blowers and other equipment associated with pre-processing and digestion. Parasitic loads listed by digester technology companies range from 5-50% of the total energy produced (SMUD, 2008). Although the exact parasitic load will be dependent on the pre-processing and digester equipment chosen, in this analysis it is assumed to be ~25% of the net electricity produced.

The estimated energy potential for the organic waste digester project was calculated as follows:

$$\frac{\text{ft}^3 \text{ biogas}}{\text{year}} * \frac{\text{MJ}}{\text{ft}^3 \text{ biogas}} * \frac{\text{kWh}}{\text{MJ}} = \frac{\text{kWh}}{\text{year}}$$

Then,

$$\frac{\text{kWh}}{\text{year}} * 0.35 \text{ generator electrical efficiency} * 0.75 \text{ parasitic load of AD system} = \text{net } \frac{\text{kWh}}{\text{year}}$$

Current waste management parameters

Understanding the existing waste management strategy is critical when making a case for developing an alternative waste processing system. Currently, the solid waste generated in Humboldt County is hauled an average of 380 miles (roundtrip) to either Dry Creek landfill in southern Oregon or to Anderson landfill in eastern California. HWMA waste disposal records track the quantity of waste going to each landfill. The cost for transporting and disposing Humboldt County's waste come directly from HWMA's contractual agreements for long-distance hauling with Bettendorf Trucking and the long-term contracts for waste disposal at the two landfills.

In order to estimate the future cost of the long distance waste hauling, the average 20 year fuel escalation rate was calculated.[83] The average annual fuel escalation rate over the period of time spanning from March 1990 to March 2010 was 2.5%. Given that fuel is 32% of the cost of long distance hauling, the long-term cost of hauling was found to be very sensitive to increases in the price of diesel fuel.

In addition to the fuel escalation rate, both the hauling charges and the landfill disposal rate increase annually with the Consumer Price Index (CPI). The hauling charges increase at 75% of CPI and the landfill disposal costs increase at 100% of CPI. The 10 year average annual rate of change for the CPI was obtained from Bureau of Labor Statistics was 2.6% (December 1999 to December 2009). This information was used to establish the baseline waste management scenario in order to draw a comparison between the lifecycle cost of the food waste digester project and the business-as-usual scenario.

Markets for end products

There are several end-products that can be generated from a digester project: electricity, heat, vehicle fuel, and soil amendments. In this analysis it was assumed that the bio-gas would be used to generate electricity and heat due to the demand for both at the Eureka WWTP. The market value for the electricity generated is two-fold. First, revenues can be generated from the sales of electricity to the treatment plant in lieu of utility grid electricity purchases. It is assumed that the electricity sold to the Eureka

[83] The 20 year average fuel escalation rate is based on data available from the US Energy Information Agency and encompasses the years spanning February 1990 to February 2010.

WWTP will be at a lower price than the Public Utility rate ($0.10 / kWh vs. an average of $0.14 / kWh). This assumption was made for model simplicity; however, when the project is established, the power will likely be sold at a floating rate that is one to two cents below the PG&E rate on a time of use basis.

The annual electricity demand at the treatment plant was obtained directly from WWTP records as well as PG&E records. In 2008 the WWTP purchased 937,040 kWh from PG&E. The revenues from selling electricity to the WWTP were calculated as follows:

Annual demand at WWTP (kWh) * $0.10 / kWh =

Annual Revenues ($) from sales of electricity to the WWTP

I assumed that the excess electricity (that which exceeds the demand at the WWTP) will be sold to Pacific Gas & Electric under the existing California Public Utility Commission's (CPUC) Feed-in Tariff (Appendix H). The annual value of the excess electricity sales was calculated by creating a model of the annual energy use and charges at the WWTP. PG&E, the local utility company, provided records of the historic 15 minute average electricity demand at the Eureka WWTP.[84] The annual net energy generation potential (from the biogas) was divided into 15 minute intervals. For every 15 minute period, the difference was taken between the demand and the additional power supplied (i.e., the renewable electricity produced from the biogas). If there was a deficit,

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[84] The Eureka WWTP is on PG&E's E-19vs "large commercial" rate schedule.

then the applicable rate was applied to the quantity of power demanded from PG&E.[85] When there was excess power, the power was sold to PG&E under the CPUC Feed-in Tariff rate schedule. The sales and purchases were summed to show the annual total energy revenues or expenditures.

The results of the model were then incorporated into the economic analysis as annual revenues from energy sales to PG&E. Additionally, the model was used to calculate the reductions in peak energy use at the WWTP which results in decreased peak demand charges. Demand charges are fees that are added to the electricity bill in addition to the energy use charges. These fees are based on the highest amount of energy demanded during the five different Time of Use periods throughout the year. These charges range from $1.00/kW to $12.30/kW. These charges can be quite substantial. For example, in 2007 and 2008, demand charges accounted for 32% and 22% of the treatment plant's total energy bill respectively ($46,000 and $28,000 per year). At a food waste collection rate of 10,000 tons per year, the resulting energy generated would reduce the demand charges to approximately $5,500 per year.

Other markets that can provide revenues to the food waste digester facility are offset natural gas (heat) purchases, sales of compost or liquid fertilizer feedstock, as well as sales of carbon offsets to the emerging carbon markets.

[85] Under the E-19 rate schedule, rates are based on the "Time of Use." For example, rates are highest during the summer months between the hours of 12pm and 6pm. Conversely, rates are lowest during the winter months between the hours of 9:30pm and 8:30am. There are five separate rates based on the time of year and time of day that the power is purchased.

Greenhouse gas reductions

Because food waste is the major source of methane formation in landfills, there are substantial Greenhouse gas (GHG) emission reductions to be gained by diverting this waste away from the landfills to a dedicated food waste processing facility. The Chicago Climate Exchange (CCX) and the Climate Action Registry (CAR) Organic Waste Digestion protocols were consulted to assess the GHG reduction potential for these projects.[86] These protocols establish the base case from which a project can claim "additional" carbon offsets (reductions from business-as-usual case) that can be sold on the market. The emission offsets that can be achieved under the CCX and CAR protocols can be seen in Table 8.5 and Table 8.6.

Table 8.5 Baseline greenhouse gas reductions achieved by diverting food waste from landfills

CCX: Baseline Emissions Reductions for Offsets for Food Waste Diverted from Landfills											
year	1	2	3	4	5	6	7	8	9	10	Total
$MTCO_2e$ per wet ton	0.255	0.211	0.174	0.036	0.03	0.025	0.02	0.017	0.014	0.012	0.794

[86] The CCX protocol is available online at: http://www.chicagoclimatex.com/docs/offsets/CCX_Avoided_Emissions_Organic_Waste_Disposal_Final.pdf .

Table 8.6 Baseline greenhouse gas reductions achieved from avoided landfilling

CAR: Baseline GHG Emissions Reductions for Food Waste Diverted from Landfills (Equation 5.3)											
year	1	2	3	4	5	6	7	8	9	10	Total
$MTCO_2e$ per wet ton	0.22	0.183	0.152	0.032	0.026	0.022	0.018	0.015	0.013	0.01	0.692

The total offset over ten years (the limit for receiving offset credits) under the CCX and CAR systems is 0.794 and 0.692 metric tons of carbon dioxide equivalent per wet ton of food waste (CCX, 2009; CAR, 2009). For this analysis, the potential GHG reductions associated with avoided landfilling were calculated using the CAR protocol values because they are more conservative. As an example, a food waste collection rate of 10,000 tons per year would reduce approximately 40,000 $MTCO_2e$ over ten years (Table 8.7)

Table 8.7 Sample calculation of GHG offsets using the CAR methodology

$MTCO_2e$ Reduced										
Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	1,551	1,289	1,071	223	185	154	128	106	88	73
2		1,551	1,289	1,071	223	185	154	128	106	88
3			1,551	1,289	1,071	223	185	154	128	106
4				1,551	1,289	1,071	223	185	154	128
5					1,551	1,289	1,071	223	185	154
6						1,551	1,289	1,071	223	185
7							1,551	1,289	1,071	223
8								1,551	1,289	1,071
9									1,551	1,289
10										1,551
						Total $MTCO_2e$ over first 10 years				**40,197**

Under both protocols, carbon offsets for food waste diverted from landfills can only be credited if there are no existing regulations mandating diversion, and the offsets are only credited for 10 years. Furthermore, any carbon offsets sold on the market cannot be claimed towards a community's GHG reductions goals. The value for carbon offsets is currently very low in the US market. This is due to the lack of mandatory emissions reductions goals set at either the state or federal level. The difference between the current voluntary market in the U.S. and the mandatory market in Europe can be seen in the values of the carbon offsets. As an example, the current Chicago Climate Exchange price is \$0.10/$MTCO_2e$ and the current European Climate Exchange price is \$20/$MTCO_2e$ (as of March 1, 2010). Revenues from the sale of carbon offsets were not included in the economic analysis as the U.S. market is still in development.

Additional GHG reductions can be realized from offset trucking and offset grid electricity use. While these offsets cannot be sold on the market, they can be counted towards a community's GHG reduction goals. These GHG reductions were calculated as follows:

For offset long haul trucking of food waste:

$$\frac{\text{Tons food waste diverted}}{\text{year}} * \frac{\text{truck trip}}{23\text{ tons}} * \frac{\text{miles}}{\text{truck trip}} * \frac{\text{gallon}}{\text{miles}} * \frac{\text{lbs. } CO_2}{\text{gallon diesel}} = \frac{\text{lbs } CO_2 \text{ avoided}}{\text{year}}$$

For offset grid electricity:

$$\frac{\text{net kWh generated}}{\text{year}} * \frac{\text{lbs. } CO_2}{\text{kWh (PG \& E grid)}} = \frac{\text{lbs. } CO_2 \text{ offset}}{\text{year}}$$

Economics[87]

Many factors were taken into consideration in the economic analysis. These include: estimated capital costs, operation and maintenance costs, permitting requirements, engineering and site preparation costs, and well as a contingency factor to account for implementation and unforeseen costs. A life cycle cost (LCC) analysis is included to compare options over their useful life. In this case, the LCC analysis of the food waste digester facility is compared to the LCC of In-vessel composting and a business as usual case that involves continued long distance hauling of waste.

The key economic assumptions that underlie the LCC calculations can be seen in Table 9.8. The capital cost for the project was constructed by obtaining cost estimates for the requisite components and adding in a 30% contingency factor for implementation and unforeseen costs. The Operation and Maintenance costs were taken from an average value of O&M costs cited by project developers who responded to a Sacramento Municipal Utility District Solicitation of Interest (SOI). This SOI was for a 12,000 ton per year food waste digester. The average value was $350,000 or $29/ton (SMUD, 2008).

[87] The equations used in the economic analysis can be found in Rubin, (2001).

The present value for all costs was calculated in order to compare the food waste project to the business-as-usual scenario. The present value for the capital costs is as follows:

$$\text{Present Value (PV)} = \text{Future Costs (\$)} * \left(\frac{1}{(1+\mathrm{i})^{n}} \right)$$

where:

i = the discount rate (%)

n = the year that the future cost or revenue occurs (year)

The present value for the operation and maintenance costs and annual energy and tipping fee revenues was calculated using the uniform present value formula:

$$\text{Uniform Present Value (UPV)} = \text{Continual costs (or revenues) (\$)} * \frac{\left(1 - (1+\mathrm{i})^{-n}\right)}{\mathrm{i}}$$

where:

i = the discount rate (%)

n = year that the future cost or revenue occurs (year)

The life cycle cost (LCC) of the food waste digester and composting systems were calculated as follows:

For the digester system:

$$LCC = NPV((Cost_{C} + Cost_{Eqpt.} + Cost_{O\&M} + Cost_{Diesel}) -$$

$$(Revenue_{E} + Offset\ Costs_{E} + Revenue_{Tip\ Fee}))$$

For the in-vessel composting system:

$$LCC = NPV(Cost_{C} + Cost_{Eqpt.} + Cost_{O\&M} + Cost_{E} + Cost_{Diesel})$$

Where:

LCC = Life Cycle Cost ($)

NPV = Net Present Value, or sum of the present values of all future cash flows

$Cost_{c}$ = Present Value of Capital cost for system technology and auxiliary equipment

$Cost_{Eqpt}$ = Present value of all equipment replacements at end of expected lifecycle

$Cost_{O\&M}$ = Uniform Present Value of annual Operation and Maintenance costs

$Cost_{Diesel}$ = Uniform Present Value of diesel fuel purchases

$Cost_{E}$ = Uniform Present Value of electrical energy purchases

$Revenue_{E}$ = Uniform Present Value for energy revenues

Offset $Cost_{E}$ = Uniform Present Value of offset energy purchases (heat)

$Revenue_{Tip\ Fee}$ = Tipping fees from fats, oils and grease disposal at the facility

Neither the composting nor the digestion project LCC analyses include a revenue stream for fertilizer sales or carbon credits.

The LCC of the business-as-usual scenario was calculated by summing the annual present value of the combined hauling and landfill disposal costs as seen in Appendix I.

The tipping fee is the cost required to cover all remaining annual costs of a project once revenues have been accounted for. This was calculated as follows:

$$\text{Tip Fee (\$/ton)} = \frac{(\text{Annualized Capital Costs} + \text{Annual O \& M Costs} - \text{Annual Revenues})}{\text{Tons food waste processed per year}}$$

The annual cost for amortization of the capital costs was calculated using the following formula:

$$\text{Annualized Capital Cost} = \text{Total Capital Cost (\$)} * \left(\frac{\text{i}}{1 - (1+\text{i})^{-\text{n}}} \right)$$

where:

i = the discount rate (%)

n = year that the future cost or revenue occurs (year)

The next chapter describes the results of the analyses that were used to determine the feasibility of a food waste diversion program.

CHAPTER 9. FEASIBILITY STUDY RESULTS

The anaerobic digestion of organic waste streams can increase the percentage of waste diversion in Humboldt County, generate renewable energy, and reduce greenhouse gas emissions. The implementation of a regional food waste digester facility would result in savings for Humboldt County in the form of lower organic waste disposal fees (tipping fees) and could save the City of Eureka money in reduced electricity charges. Furthermore, a regional food waste digester will generate revenues which can be used to offset capital and operating costs of the facility. A lifecycle cost comparison indicates that the cost of developing and operating a food waste processing facility is competitive with the cost of in-vessel composting and less expensive than that the cost of continuing to haul the same waste to the landfills over a 20-year time horizon.

There are many co-benefits associated with establishing a local food waste processing facility. First, this facility will re-direct monies spent on out-of-county disposal back to Humboldt County. For example, Humboldt County currently realizes no benefit from the sales of electricity derived from the landfill gas at the landfills that receive the County's food waste. Second, generators of other organic waste streams can also benefit from the convenience and lower cost of local processing and disposal.[88] In this analysis, the additional organic waste streams considered include fats, oils, and grease collected from sewer from the manufacture of biodiesel, and cheese whey from a

[88] As an example, Footprint Recycling and other waste oil collection companies haul the fats, oils and grease (FOG) (~295 miles) to the San Francisco Bay area or to Chico, CA for processing and disposal. Lower costs for waste grease haulers could also result in lower costs for restaurants and facilities that require waste grease collection.

local factory producing goat cheese.[89] Finally, building a food waste digester facility will create local jobs, and Humboldt County's waste management system will become less vulnerable to fluctuations in the price of diesel fuel.

The following sections outline key components of the feasibility study analysis, including the costs and benefits of developing a regional food waste digester facility in Humboldt County.

Scenarios for food waste collection levels in Humboldt County

I evaluated four food waste collection scenarios to determine the economic viability of the food waste digester facility. The first three scenarios are based on collecting different portions of the total commercial and industrial food waste available in each of the cities in Humboldt County, and in the Unincorporated County areas. The fourth scenario examines the total regional potential and includes residential waste. A full description of the sources and quantities of these wastes can be seen in Appendix F.

The organic waste resources that contribute to each of the four scenarios are Humboldt County's commercial food waste, including FOG collected from local restaurants, glycerin from the manufacture of biodiesel, [90] cheese whey from goat cheese manufacturing, and the commercial food waste in the Del Norte County waste stream.[91]

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[89] See Appendix I for a list of other sources of organic waste available in Humboldt County.
[90] Quantities of FOG and glycerin available for processing were obtained directly from Andy Cooper, Owner of Footprint Recycling via personal communication July 2008, and updated August 2009.
[91] The Del Norte Solid Waste Management Authority (DMSWMA) issued an RFP in 2008 for "processing and marketing" their organic materials (DNSWMA 2008). Scenarios two through four include a capture rate of 75 to 90% of the 1,520 tpy of organic waste based on the assumption that on account of DNSWMA's organics processing RFP, the waste management agency and community are already motivated to divert food waste from the waste stream.

Table 9.1 shows a summary of the tonnage of food waste and other organics that were used to size the system and estimate the costs and benefits of a regional food waste digester facility in Humboldt County.

Table 9.1 Commercial sector food waste collection scenarios

Scenario 1 – Low food waste collection	**tons / day**	**tons / year**
Total tons per year commercial food waste only	7	1,872
Total tons per year commercial and industrial food waste	13	3,417
Scenario 2 – Medium food waste collection	**tons / day**	**tons / year**
Total tons per year commercial food waste only	19	4,884
Total tons per year commercial and industrial food waste	25	6,429
Scenario 3 – High food waste collection	**tons / day**	**tons / year**
Total tons per year commercial food waste only	30	7,756
Total tons per year commercial and industrial food waste	36	9,360
Scenario 4 - Regional potential food waste collection	**tons / day**	**tons / year**
Total tons per year commercial and residential food waste	61	15,826
Total tons per year commercial and industrial food waste	67	17,549

The only varying factor between the low and medium scenarios is an increase in food waste collection from the commercial sector. At the high level of waste collection, both the amount of food waste and FOG increase. The latter is due to the expectation that some of the other waste oil haulers in the county will choose to utilize the local processing facility instead of hauling this waste to Chico or the San Francisco Bay area.

It should be noted that the initial feasibility study includes food waste from the commercial sector and known sources of industrial sector wastes only. The commercial sector was chosen as a starting point due to the smaller number of collection points required for collecting a highly concentrated source of food waste. Once the digester facility is in place, it is likely that the availability of a low cost, local waste disposal option for organic waste will result in the eventual inclusion of residential waste as well.

The “Regional potential” scenario is included here as a reference point for the volumes of waste and resulting benefits that could be accrued if the project were to include residential waste, as well as additional sources of FOG and other industrial waste such as fish processing waste. These additional volumes would result in lower costs to the rate payers, as a greater portion of the annual costs would be met by revenues from energy sales instead of tipping fees.

System sizing

The main components to be sized in the system are the digester tanks and the preprocessing equipment and building. Digester tank volume can be estimated using the quantity of food waste collected and the rate at which the food waste can be loaded into the digesters for sustained microbial processing of the waste.[92] A list of organic loading rates that have been used to successfully digest food waste in wet systems can be seen in the Methods section (Chapter 8). The estimated digester volume for the first three scenarios is 500 m^3 (17,700 ft^3), 1000 m^3 (34,300 ft^3), and 1,400 m^3 (48,000 ft^3),

[92] It should be noted here that the nominal solids residence time of 20-25 days is imbedded in the loading rates.

respectively. A tank with a working volume of 1,500 m^3 (51,500 ft^3) would therefore be sufficient for the first phase of the food waste digester facility. Dry or high solids digestion technologies may require less digester space due to decreased water levels. If a dry system is chosen, the volume of the digester tank can be substantially reduced; in dry systems less water is added to the waste and therefore less total volume is needed.

The estimated footprint of the preprocessing building is 25 m x 25 m (80 ft x 80 ft). The total floor space is based on the footprint requirements of the pre-processing equipment, space for an office, break room, and reception area, and the space needed for trucks to maneuver during food waste delivery. The pre-processing approach chosen for this analysis is based on density separation. This process was chosen because it is successfully used to remove contaminants out of municipal food waste at the two anaerobic food waste digester facilities in Toronto, Canada. The footprint allotted to density separation equipment is based on the BTA density separation equipment.[93] The office space is based on sample floor plans for municipal offices that are Americans with Disabilities Accessible (ADA).

The space needed for receiving the food waste requires a "hammer head" truck turnaround. This space requirement was estimated using the fire truck hammerhead turn dimensions from the Life Safety Code of the City of Eureka.[94]

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[93] Information about the density separation pre-processing equipment was provided in a cost estimate provided to HWMA in December of 2007 by Canada Composting, licensed distributor of the BTA hydropulper technology.

[94] A Hammer head turnaround is one in which a truck can enter, back up at a right angle to unload, then drive forward making another right angle turn to exit from the same point of entry. This information was provided by City of Eureka Engineer Kurt Gierlich via personal communication December, 2007.

Major costs

The major costs associated with developing a food waste digestion project are the receiving and pre-processing building (includes a scale system and odor control equipment), the digester system equipment, and the auxiliary equipment (front-end loader and co-generation equipment). The estimated costs for the high waste collection scenario are shown in Table 9.2. This scenario was selected because it reflects the first phase design target for the facility. The detailed costs and sources of the estimates can be seen in Appendix G. The contingency cost includes installation and other unforeseen costs.

Table 9.2 Major costs of anaerobic digestion at 10,000 tons / year scenario

Major Costs	**$**
Operations building, scale & odor control system	$810,000
Digester system	$4,300,000
Auxiliary equipment	$270,000
Permitting	$250,000
Engineering	$110,000
Facility development	$200,000
Program design	$60,000
Sub total	$6,000,000
Contingency (30%)	$1,800,000
Total	$7,800,000

Pre-processing and processing equipment

Pre-processing is needed to prepare the food waste for digestion. Pre-processing steps include receiving the waste, removing the contaminants, and homogenizing the material (grinding). The specific equipment for pre-processing depends on the characteristics of the feedstocks going into the digester, the digester technology chosen, and the design of the waste collection program. This section describes the pre-processing building and major components included in the analysis.

The pre-processing building will house the waste delivery area, the pre-processing equipment, an office, a lab space, and odor the control equipment. The pre-processing facility design includes one 50ft scale with two card-reader kiosks. This enables a truck to enter, weigh, back into the receiving bay, drop off the food waste, then pull forward and leave via the same scale with a card reader to record the exit weight. The weight records will be used to track food waste diversion and greenhouse gas emissions reductions for each jurisdiction.

Pre-processing municipal food waste streams is a relatively new phenomenon, and as such there are a variety of treatment train technology choices. Further, the technology chosen depends greatly on the quality of the waste feedstock as well as the digester technology chosen. The grinding and contaminant removal equipment chosen for this analysis are the density separator and grinder equipment currently available on the market.

The odor control system consists of blowers that remove the foul air from the pre-processing building and move it through bio-filters. The basic concept of bio-filtration is to have odorous air flow through media that provide a substrate supporting microorganisms. Bio-filters can be in the form of cylinders or beds of woodchips, finished compost, or other packed media. Organisms that consume, or degrade, the specific odorous compounds in the air stream accumulate on the media and multiply. As the air is passed through the bio-filter, the organisms consume the volatile organic compounds that cause odors and the air is de-odorized.[95]

The total digester costs are based on the volume required to process the quantity of food waste collected at each scenario. The economic analysis includes prices for processing equipment such as pumps, mixers, screens, and gas collection equipment. Firms with experience building this type of project provided engineering and permitting cost estimates. Finally, the analysis includes a 30% contingency factor to anticipate unforeseen costs and installation.

Operation and maintenance costs

For this analysis the total operation and maintenance (O&M) cost estimate is $340,000 per year. This number is based on known annual fees as well as estimates for labor, insurance, and equipment maintenance. I compared this value to O&M cost estimates generated in a 2008 Statement of Interest (SOI) solicitation for a 12,000 ton per day food waste digester system. The average O&M cost estimates from the vendors who responded to the SOI was $350,000 per year, differing from the HWMA facility estimate

[95] The odor control system used in this economic analysis was sized by Bay Products, Inc., odor control specialists. A description of bio-filtration systems they offer can be found at their website: http://www.bayprod.com/third-page/26.

by $10,000 (SMUD, 2008). The size of the system proposed in the SOI is slightly larger than the system proposed for Humboldt County (12,000 tons/year vs. 10,000 tons/year), and therefore I determined the estimated O&M value used in this analysis to be reasonable. This section describes the O&M cost estimate components. See Appendix H for an itemized list of the annual O&M costs.

The O&M cost calculation includes the known permitting fees for solid waste facilities as well as wastewater disposal permits. I estimated labor charges using the existing employee wage levels at the wastewater treatment plant and at HWMA. The initial workforce will include three facility operators and one supervisor.[96] As the project expands, the number of employees will expand accordingly. The operators' duties will include initial load inspection for approximately eight to ten truckloads per day,[97] operation of pre-processing equipment, and monitoring the digester performance on a daily, weekly and monthly basis. Daily testing includes the measurement of CO_2 gas concentration (an indicator of the CH_4 gas production), pH, and temperature. Weekly sampling and lab testing of the inlet and outlet sludge will give an indication of the volatile solids destruction efficiency. Monthly testing will include measuring the H_2S gas concentration. In addition to these tests, operators will be responsible for monitoring the performance of the gas treatment equipment and the odor control equipment as well as responding to, and keeping a record of, odor complaints.

[96] This estimate assumes each employee is working forty hours per week.
[97] City Garbage Company of Eureka (Recology) gave a value for 6,000 pounds (three tons) per truck for food waste collected in a rear loading garbage truck (Wise 2009). The eight to ten loads per day estimate is based on the quantity of food waste collected daily at the high scenario and intermittent FOG pumper truck deliveries.

I have assumed the insurance costs to be equal to the annual insurance costs associated with operating the HWMA Hawthorne Street transfer station. Equipment maintenance costs are assumed to be $0.02 per dollar of initial equipment cost. Residual solids management costs come directly from the current compost processing costs at the HWMA Mad River compost facility. It should be noted here that not all costs listed would be incurred by the food waste digester facility. For example, the cost of residual management may not be needed if the residual is sold and processed into liquid fertilizer.[98]

Energy, Savings, and Revenues

Food contains calories, or energy captured from the sun, that we use to run our bodies. One of the primary goals of this project is to utilize the energy bound up in the food that is disposed to offset the costs of processing this waste. I estimated the revenues derived from the sales of renewable energy by calculating the amount of electricity that could be generated from anaerobically digesting the food and other organic wastes in the region.

The energy potential of this project could power the equivalent of over 350 typical California households per year.[99] As the project grows to accept additional food processing wastes and/or residential food waste, the renewable energy generation will

[98] HWMA has already been contacted by Eco Nutrients, a liquid fertilizer manufacturer in Del Norte County, for the purpose of utilizing the digested food waste residual as a feedstock for their product. Under this scenario, an additional revenue stream can be realized from the sale of the residual, rather than a cost for residual processing.

[99] This calculation is based on the average California household energy use of 7,032 kWh per year (California Energy Commission 2008).

also increase. Table 9.3 shows the energy production potential relative to increasing food waste collection for the four scenarios. Refer to the methods section (Chapter 8) for the calculations that generated these values.

Table 9.3 Energy Production Potential

Energy Production Potential				
Scenario	**Tons waste per year**	**Ft^3 Biogas per year**	**MWh/year**	**# CA house equivalents**
Low	3,400	18,000,000	990	140
Medium	6,400	32,000,000	1,800	250
High	10,000	45,000,000	2,500	350
Regional	18,000	83,000,000	4,500	650

The most efficient use of this resource is to provide heat and power for onsite loads. Using electricity close to where the loads are located minimizes inefficiencies due to transmission line losses. The WWTP has an annual grid electricity demand[100] of 1,050 MWh that can be offset in whole or in part by the electricity generated from the food waste digester project.

In 2008, the WWTP generated 41% (715 MWh) of its total onsite power demand (1765 MWh / year)[101] with the electricity generated from the existing co-generation system. The cogeneration system is fueled by the digester gas from the two municipal sludge digesters as well as a small amount of natural gas that the WWTP purchases

[100] This is the amount of electricity that the WWTP purchases from PG&E annually.
[101] This is the total electricity demand at the WWTP, a portion of which is met by the onsite co-generation engines, and the remainder is purchased from the PG&E grid.

during the coldest months of the year.[102] In this analysis I have assumed that the food waste digester facility will purchase a 250 kW internal combustion co-generation engine. The electrical energy generated from the digester gas will be consumed by the treatment plant, and any excess will be sold to the electric utility grid.

Because there will still be times of day where the treatment plant demand is greater than the onsite supply of electricity, the WWTP will continue to incur demand charges under their E19vs rate schedule.[103] Demand charges are fees based on the highest average 15 minute demand (kW) during each of the peak periods[104] as well as the highest average 15 minute demand over the entire day. This charge is in addition to the charges for actual electricity use. For example, of the $129,332 paid in electricity charges in 2008, 22% ($28,443) came from to demand charges. The electricity generated from the food waste biogas can reduce the demand charges at the WWTP. Table 9.4 shows the potential for demand charge reductions.

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[102] Natural gas is purchased during the coldest months to supplement the digester gas, needed to run the two co-generation engines simultaneously in order to heat the digesters.

[103] i.e., although the remaining net annual electricity demand at the WWTP (kWh / year) can be met by the additional energy generated from the food waste digester, there will still be daily spikes of high demand that will outpace the onsite generation capacity.

[104] High peak purchasing periods are summer weekdays from noon until 6 pm. Partial peak purchasing periods are weekdays 8:30 am until 9:30 pm with the exception of high peak pricing hours during the summer weekdays. Off peak periods are 9:30 pm to 8:30 am all days. Electricity rates correspond to the time of day due to the levels of demand placed on the grid during those times. PG&E rate schedules can be accessed at: http://www.pge.com/tariffs/ERS.SHTML#ERS .

Table 9.4 Estimated annual savings from reduced peak loads

Scenario	Reductions in annual Demand Charges
Low	$5,000
Medium	$18,000
High	$25,000
Regional potential	$28,000

According to the economic model generated for this analysis, if the project receives a minimum of 5,400 tons of mixed organic waste per year, the entire electricity demand at the WWTP facility will be met. This can be seen in Figure 9.1. Once the food waste derived electricity exceeds the WWTP demand, the excess electricity can then be exported to the PG&E electricity network. As of March 2008, PG&E is required by the California Public Utilities Commission (CPUC) to offer a feed-in tariff,[105] or Standard Contract for Purchase, for excess electricity produced at publicly owned wastewater treatment plants or other renewable electricity generation facilities.

[105] A Feed-in Tariff is a fixed price paid by the utilities for electricity fed into the grid ($ / kWh).

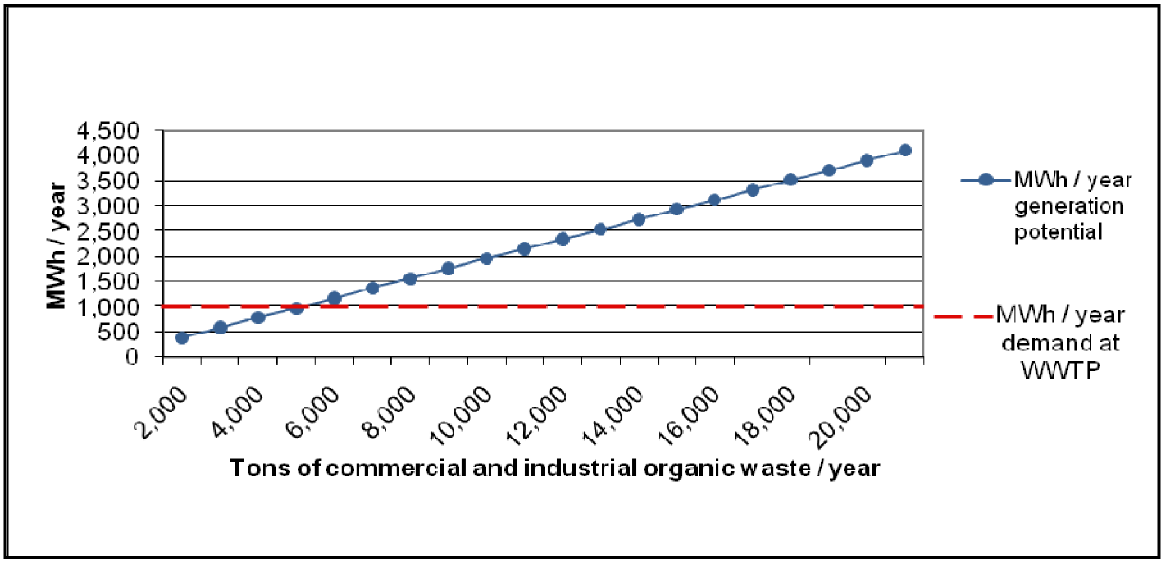

Figure 9.1 This figure shows the electricity generation potential as a function of diverted food waste. The intersection of the blue and red lines is the quantity of food waste that needs to be collected in order to meet the remaining demand at the Elk River WWTP.

The rate offered for the electricity is based on a Market Price Referent, which is the avoided cost of obtaining electricity from a natural gas turbine combined-cycle generator. A more detailed description of this feed-in tariff can be found in Appendix I. Current rates for selling electricity back to PG&E can be seen in Table 9.5. For comparison, the PG&E Large Commercial (E-19vs) rate schedule is included in Table 9.6.

Table 9.5 Rates paid for renewable electricity fed into the grid

Feed-in Tariff ($ / kWh)			
	Super-Peak	Shoulder	Night
Period:	12p - 8p m-f	6a - 12p, 8p-10p m-f; 6a - 10p Sa-Su, NERC[106]	10p - 6a all days including NERC
Jun - Sept.	$0.22	$0.13	$0.08
Oct. - Dec., Jan. - Feb.	$0.12	$0.11	$0.09
Mar. - May	$0.13	$0.10	$0.07

Table 9.6 Rates that the Elk River WWTP pays for electricity

PG&E E-19vs rate Schedule Oct. 2009 to present:			
Summer	**On Peak**	**Partial Peak**	**Off Peak**
May 1 - Oct 31	12p - 6p	8:30am - 12p, 6p - 9:30p	9:30p - 8:30am
$ / kWh	$0.15592	$0.10595	$0.08545
Winter		**Partial Peak**	**Off Peak**
Nov 1 - April 30	n/a	8:30a - 9:30p	9:30p - 8:30am
$ / kWh		$0.09387	$0.08228

When compared to the current rates paid for electricity at the wastewater treatment plant, the feed-in tariff rates paid to renewable energy generators are ~ $0.03 / kWh more on a typical summer weekday than the price of purchasing the same

[106] The "NERC" holidays are electricity price holidays that occur on the following holidays: New Year's Day, Memorial Day, Independence Day, Labor Day, Thanksgiving Day, and Christmas Day. Details can be seen at: http://www.pge.com/includes/docs/pdfs/b2b/energysupply/wholesaleelectricsuppliersolicitation/ELEC_FORMS_79-1102%20(2009%20MPR).pdf .

amount of energy.[107] During peak pricing periods, the value of the electricity sold to the grid can be as much as $0.07 / kWh more than the rate paid for the same amount of electricity. During off-peak pricing periods, the feed-in tariff rate is only ~$0.01 / kWh more than the purchase price of that same energy. Considering this pricing scheme (i.e., in order to maximize revenues), a gas storage system should be considered as part of the project development.[108]

The price paid for feeding renewable electricity into the grid is a key component in the economics and feasibility of developing digester projects. The widespread adoption of food waste digesters in Europe is partially credited to the high feed-in tariff offered for renewable electricity (CIWMB, 2008a). As California and/or the United States adopt climate change mitigation strategies, the value of this renewable energy is likely to rise, and, consequently, the economic feasibility of this type of project will improve.

I modeled the effect of adding electricity generation capacity to the WWTP system using the annual electricity demand data from the Eureka Elk River wastewater treatment plant.[109] I combined the WWTP demand profile data with PG&E's E-19vs rate schedule[110] (Table 9.6) to determine how much the WWTP paid for every 15 minutes of

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[107] Electricity charges used in this analysis are based on the PG&E E-19vs Large Commercial rate schedule.

[108] Gas storage would allow for the maximum amount of energy to be sold to the grid during the peak pricing periods.

[109] Data used in the analysis included two years of monthly average and total annual usage provided by the Eureka Elk River WWTP, as well as one year of 15 minute average demand (at the WWTP) provided by PG&E.

[110] The WWTP is billed for electricity under the PG&E Large Commercial rate schedule E19vs. This rate schedule includes a demand charge, an electricity use charge, and a flat-rate customer charge. The electricity use charges vary based on the time of day. Electricity is more expensive during the periods of highest peak demand on the grid (weekdays from 12pm until 6pm), and least expensive during off peak (lowest) demand periods (i.e., nighttime, 9:30pm – 8:30am).

electricity demand throughout the year. These costs were then adjusted to reflect the increased onsite electricity generation from the food waste digester gas. I estimated the increased onsite electricity generation by dividing the annual net electricity generation potential evenly over 15 minute intervals throughout a year, assuming constant generation. Using the combination of demand data and generation potential, I was able to model the cost or revenue associated with each 15 minute interval throughout the year. For example, if during a given 15 minutes the treatment plant's demand is greater than the total supply, then the applicable Time of Use rate was applied to the remaining demand for that time period. Conversely, if the total supply exceeds the WWTP demand, then the feed-in tariff rate was applied to the excess power going into the utility grid. At the end of the year, the charges and revenues for each 15 minute period are summed, and the net revenue or remaining electricity charges are quantified. The revenues that can be generated from the sales of renewable electricity to the WWTP and PG&E can be seen in Table 9.7.

Table 9.7 Estimated revenues from renewable electricity sales

Scenario	Revenues from sales of electricity to WWTP ($/year)	Revenues from excess electricity sales to the PG&E grid ($/year)
Low	$74,078	$0
Medium	$105,046	$31,773
High	$105,046	$92,771
Regional	$105,046	$264,405

At all but the lowest level of food waste collection, the remaining electricity demand at the treatment plant can be met, and revenues from renewable electricity sales to the utility can be realized.

Economic analysis

The economic feasibility for the regional food waste digester is based on the cost per ton to process the waste ($/ton) as well as the overall cost of the facility over the 20 year planning horizon. The assumptions used in the analyses that follow can be seen in Table 9.8.

Table 9.8 Key economic assumptions for the proposed digester system

Description	Value
Planning horizon	20 years
Discount rate	5%
CPI 10 yr. avg. inflation rate	2.6%
Avg. 20 year fuel escalation rate	2.5%
O&M cost[111]	$34 / ton
Implementation contingency factor	30% of total capital
Average electrical power cost to WWTP ($ / kWh)	$0.14
Tipping fee brown grease and grease trap waste[112]	$0.15
Solids management cost ($ / ton)[113]	$41

[111] This value was generated as part of this analysis and can be seen in Appendix H.
[112] This value is the current rate for processing FOG at the EBMUD facility. Current rates can be seen at: http://www.ebmud.com/our-water/wastewater-treatment/wastewater-treatment-programs/wastewater-rates-charges-and-fees#trucked%20fees
[113] This fee is based on the current compost processing cost at HWMA's Mad River Compost facility.

Another factor that influences the feasibility of developing a regional food waste digester facility is the savings in the form of reduced long distance hauling charges. These savings will be a net benefit to the community as they will help to stabilize waste management rates through decreased vulnerability to fuel price fluctuations. The sections that follow describe the results of the economic analysis that was used to determine the feasibility of developing a food waste digester facility compared to other waste management options.

Waste Disposal Fee (Tipping fee)

A tipping fee is the cost required to dispose waste. A comparison of the current HWMA waste disposal tipping fee to the tipping fee associated with the food waste digester facility is shown in Table 9.9. In the high collection scenario the digester project is feasible compared to current landfilling costs. The high scenario is therefore the target base collection volume for all other comparisons.

Table 9.9 Comparison of the tipping fee required to meet annual costs at the digester facility vs. the current cost to dispose waste in Humboldt County ($/ton).

Scenario	Tipping fee food waste digester ($/ton)	Tipping fee with HWMA county-wide fees ($/ton)	Current tipping fee for franchise haulers ($/ton)
Low	$290	$317	$129
Medium	$132	$159	
High	$95	$122	
Regional	$63	$90	

The Hawthorne Street Transfer station tipping fee cost includes the cost of hauling and disposing waste at the Anderson and Dry Creek landfills. Also included in this fee is the cost of operating the transfer station including overhead, insurance, labor and “county-wide fees;” these are fees designed to cover illegal dumping and waste reduction programs, such as hazardous waste and electronic waste disposal.

Included in the tipping fee for the Food Waste Digester project is the amortized cost of the initial capital investment and the annual operating costs including overhead, insurance and labor. As the project scale increases beyond 5,000 tons per year of organic waste, the digester facility tipping fee is lower than the fee for conventional waste disposal. For comparison, two food waste digester facility tipping fees are shown: one that shows the cost to process the waste only, and one that shows the cost if County-wide fees are included. It is not clear whether HWMA will add all or any of the additional county-wide fees to the food waste digester tipping fee as the fees are used to fund waste diversion programs, and the food waste digester is a waste reduction program itself.

The following revenue streams were not included in either the lifecycle cost or the tipping fee calculations due to commodity market and pricing uncertainty:

- Revenues from the sale of liquid fertilizer
- Revenues from compost sales
- Revenues from carbon credit sales (this will be explored in the next section)

Although they are not included in this analysis, it should be noted that the residual digested solids and liquids can be converted into a value-added fertilizer, and can generate an additional revenue stream that will help to keep overall tipping fee low. The revenues to be gained from the sale of this product depend on the costs of processing and the market value, both of which will be factored in as the project progresses. Another revenue stream could be realized from the sale of carbon offset credits. This too will depend on the market value when the project is operational.

Life Cycle Cost Analysis

The purpose of a life cycle cost analysis is to compare two or more options based on the total cost of each option over the same planning horizon. This analysis compared the lifecycle cost (LCC) of the proposed regional food waste digester facility to the lifecycle cost of in-vessel composting and continued hauling of food waste to the landfills. The LCC analysis assumes 10,000 tons per year organic waste collection (i.e., the high collection scenario), a discount rate of 5%, and a planning horizon of 20 years.

The results of the analysis indicate that the regional food waste digester has a lower lifecycle cost compared to in-vessel composting and the business-as-usual case. In-vessel composting is also less expensive than long distance hauling, but is more expensive over the lifecycle than anaerobic digestion. The latter result is due to the higher operation and maintenance costs associated with in-vessel composting as well as the recurring annual diesel fuel and electricity costs. Long distance hauling is the most expensive option due to the heavy reliance on diesel fuel.[114]

Included in the life cycle cost of the food waste digester option are the capital cost, annual operation and maintenance costs, and potential revenues from energy sales and liquid waste tipping fees. The in-vessel composting LCC was based on the average capital cost, operation and maintenance cost, and equipment energy demand values provided to HWMA in response to a request for information (RFI) for a 10,000 ton per year in-vessel composting facility (HWMA, 2010). The LCC analysis for the business-as-usual case is based on the HWMA solid waste hauling contract. The cost of waste hauling in the future increases with fuel costs using the 20 year average fuel escalation rate for diesel fuel.[115] Landfill disposal fees of $24/ton and the transfer station processing costs ($38.37/ton) are also included in the total cost.

For comparison to the anaerobic digestion case, the major costs of in-vessel composting systems can be seen in Appendix J. The in-vessel composting LCC analysis based on these costs can be seen in Appendix K. The anaerobic digestion LCC can be seen in Appendix L, and the business-as-usual LCC analysis can be seen in Appendix M. A comparison of the results from these analyses is shown in Table 9.10.

[114] Currently fuel charges constitute 32% of the total waste disposal cost in Humboldt County; the cost of waste hauling is therefore directly impacted as fuel costs rise.
[115] Historic and current U.S. fuel prices can be accessed at the U.S. Energy Information Agency website: http://www.eia.doe.gov/emeu/steo/pub/fsheets/real_prices.xls .

Table 9.10 Life cycle cost comparison of food waste management alternatives with a 10,000 ton per year capacity.

20 year Lifecycle cost (LCC)		
	Lifecycle cost of food waste management option	Lifecycle cost relative to long distance hauling
In-vessel compost facility (Million $)	$14,000,000	-$1,000,000
Anaerobic digestion facility (Million $)	$9,400,000	-$5,600,000
Business as usual: haul to landfill (Million $)	$15,000,000	n/a

Both in-vessel composting and anaerobic digestion have a lower lifecycle cost compared to long distance waste hauling. Therefore, managing food waste via either form of diversion will benefit Humboldt County ratepayers over the long term. This is mainly due to the offset cost of long distance hauling. In the case of anaerobic digestion, the lifecycle cost is further reduced by revenues accrued from renewable energy sales.

Furthermore, the results indicate that the overall lifecycle cost of solid waste management in Humboldt County could be reduced if a local food waste diversion facility is established. The overall lifecycle cost comparison can be seen in Table 9.11.

Table 9.11 Total Lifecycle Cost comparison of Humboldt County waste management strategies. The first two strategies include a 10,000 ton per year food waste diversion program in addition to hauling the remaining waste stream to the landfill (i.e., business as usual).

20 year Lifecycle Cost	
	Total LCC of Humboldt County waste management strategy
In-vessel compost facility + haul remaining waste to landfill (Million $)	$105,000,000
Anaerobic digestion facility + haul remaining waste to landfill (Million $)	$100,000,000
Business as usual: haul all waste to landfill (Million $)	$117,000,000

Diverting and locally processing the food waste portion of the waste stream can help to stabilize waste disposal rates over time by the reducing the County's vulnerability to the increasing cost of fossil fuel. As the cost of fuel increases, the cost of hauling waste to the landfills also increases.[116] Although it is difficult to predict the exact rate of increase for future fuel prices, the inevitable peak in global oil supply coupled with a rising global population and economic expansion ensure that fuel prices will continue to rise at an increasing rate over time. Therefore, the fuel escalation rate used to calculate the life cycle cost of the business-as-usual waste management strategy may prove to be conservative.

[116] In order to determine the future cost of waste management under the business-as-usual scenario, I assumed that over the next twenty years diesel fuel prices will increase at the same rate as the last 20 year average (2.5%). The average annual increase in diesel fuel prices (fuel escalation rate) can be calculated using the data available from the U.S. Energy Information Administration's historic fuel prices database: http://www.eia.doe.gov/emeu/steo/pub/fsheets/real_prices.xls.

In general, all fossil fuel derived energy prices are projected to rise over time. As this happens, anaerobic digestion of food waste becomes increasingly economically attractive while composting and long-distance hauling become relatively more expensive. However, as long distance hauling requires large amounts of fuel compared to the composting, the increase in overall cost is much greater for the business-as-usual waste management strategy.

Savings resulting from local waste processing

Processing food waste locally will result in fewer long haul trips (380 miles roundtrip) to the landfills in Medford, OR and Anderson, CA. Each truck hauls 21 tons of waste and has an average fuel efficiency of 4.6mpg. The annual savings from reduced hauling as a result of diverting food waste can be seen in Table 9.12. These annual savings are factored into the digester and in-vessel composting lifecycle cost analyses as the offset truck trips will reduce the overall cost of solid waste management in Humboldt County.

Table 9.12 Annual savings from avoided long-haul trucking

Scenario	Food Waste only (tons/year)	# offset truck trips /year (long haul)	Hauling savings ($/year)
Low	1,872	89	$62,000
Medium	4,884	233	$160,000
High	7,756	369	$260,000
Regional	15,826	754	$520,000

Reduced long-haul trucking will also help to reduce the carbon footprint associated with managing Humboldt County's solid waste as discussed in the next chapter.

CHAPTER 10. GREENHOUSE GAS EMISSIONS AND RELATIONSHIP TO AB 32

This food waste diversion project will reduce greenhouse gas emissions (GHGs) in three ways. First, carbon dioxide (CO_2) emissions will be reduced when long-haul trucking is replaced by local processing. Second, CO_2 emissions will be reduced from avoided grid electricity as a result of generating renewable electricity. Finally, uncontrolled methane emissions will be avoided when food waste is diverted away from landfills. The avoided landfill methane emissions are not only the largest reductions associated with this project, they are also a highly verifiable (therefore valuable) form of carbon offset that can be sold on the carbon market.

The Chicago Climate Exchange[117] and the Climate Action Registry[118] have established protocols for quantifying emissions reductions associated with avoided landfilling. Under these protocols, carbon offsets are spread out over a 10 year period of time in order to reflect the natural decay rate of organic materials in landfills as well as the landfill gas capture rate (CCX, 2009; CAR, 2009). These protocols assume that for the first three years, while landfills cells are still open and before gas collection systems are in place, nearly all of the methane generated is released uncontrolled into the atmosphere. For the following seven years, a 75% landfill gas capture rate is applied to the remaining gas flow (CCX, 2009; CAR, 2009). The potential emissions reductions

[117] The Chicago Climate Exchange (CCX) website is located at: http://www.chicagoclimatex.com/ .
[118] The Climate Action Registry (CAR) website is located at: http://www.climateregistry.org/ .

associated with food waste diverted from landfills can be seen in Table 10.1 below. All emissions reductions are shown on a ten year basis for comparison.

Table 10.1 Greenhouse gas emissions reduction potential associated with the Food Waste Digester project

Scenario	**Offset carbon emissions from avoided trucking ($MTCO_2e$/10 years)**	**Offset carbon emissions from avoided grid power ($MTCO_2e$/10 years)**	**Offset carbon emissions from avoided landfill gas generation ($MTCO_2e$/10 years)[119]**
Low	790	1,910	9,700
Medium	2,050	3,490	25,300
High	3,260	5,170	40,200
Regional	6,650	8,300	82,020

These reductions would enable all participating jurisdictions to reduce their overall carbon footprint as required by AB 32, The California Global Warming Solutions Act (2006). This act requires the State of California to reduce carbon emissions to 1990 levels by 2020. This will require a state-wide reduction of 169 million metric tons of CO_2 equivalent ($MMTCO_2e$)[120] by the year 2020 (CARB, 2008).[121] Under the proposed

[119] This estimate is based on the CAR protocol because it is a more conservative value (0.692 $MTCO_2e$ / ton food waste vs. 0.794 $MTCO_2e$ /ton food waste (CCX).

[120] The unit $MMTCO_2e$ is used because carbon emissions can be from many different gasses. Because the most prevalent GHG is carbon dioxide, all other gases are converted into CO_2 equivalents (based on their relative climate forcing potential) for accounting purposes. For example, methane (CH_4) is considered to be 25 times more powerful than CO_2, therefore, 1 metric ton of methane is equivalent to 25 metric tons of CO_2. Additionally, the units for carbon accounting are in metric versus imperial units, and therefore the pounds of CO_2 are converted into metric tons in order for carbon markets to use a uniform accounting system.

[121] This emissions reduction target is based on a projection that future emissions will be 596 $MMTCO_2e$ per year under the business-as-usual scenario. The California Air Resources Board developed a target of 427

scoping plan recently released by the California Air Resources Board, the waste sector accounts for 1% of California's GHG emissions (CARB, 2008). The recycling and waste sector is expected to reduce emissions by 1 $MMTCO_2e$ by 2020 through increased landfill methane capture, and an additional 9 $MMTCO_2e$ by 2020 from other measures in the waste and recycling sector including anaerobic digestion (CARB, 2008).

There is a great potential to help meet the AB 32 GHG reduction goals through organic waste diversion. For example, if 50% of the food waste in California is diverted from landfills annually (and anaerobically digested instead), the estimated emissions reduction potential is 16 to 18 $MMTCO_2e$ over 10 years (CAR and CCX respectively), or approximately 9 to 11% of the AB 32 emissions reduction target by the year 2020. These calculations can be seen in Appendix N and O. Although this potential assumes that this waste is diverted to digesters every year starting this year, the resulting percent of the AB 32 target reductions speaks to the potential for GHG reductions through appropriate waste management. The emissions reductions from reduced vehicle miles traveled (avoided hauling) and offset fossil fuel use (grid electricity) will augment the local emissions reduction impact of this waste management policy shift.

As carbon emissions caps are implemented in the United States and California, the value of carbon credits[122] will become more established. Currently, there are voluntary markets such as the Chicago Climate Exchange, the Regional Greenhouse Gas

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$MMTCO_2e$ per year by the year 2020. Therefore, a total reduction of 169 $MMTCO_2e$ is required to meet this target.

[122] A carbon credit is a financial instrument representing greenhouse gas emissions reductions. One carbon credit represents the reduction of one metric ton of CO_2. Under a cap-and-trade system carbon credits can be sold by those firms which can reduce GHG emissions to firms who need to purchase reductions in order to meet a prescribed upper threshold (cap) of emissions.

Initiative,[123] and the Western Climate Initiative.[124] The prices in these markets are currently around \$0.10-\$2.07 per metric ton CO_2e (as of April 2010). In the European Union, where a mandatory program exists, the value of a carbon offset credit is \$20 per metric ton CO_2e (as of April 2010) (CCX, 2010). The future revenues from carbon credit sales will depend on the structure of the emerging markets, but the estimated revenues shown in Table 10.2 indicate the potential revenues that could be derived from this project assuming the mandatory program's pricing. This potential revenue stream could help to reduce the tipping fee required to process organic waste. However, as the U.S. carbon market is still nascent, these revenues were not included in the economic analysis.

Table 10.2 Estimated revenues from carbon emissions offset sales derived from food waste diverted from landfills via the digester project. Values in red represent GHG reductions.

Potential revenues from sales of carbon offset credits: 10,000 ton / year facility				
	Project GHG emissions: Diesel fuel over 10 years ($MTCO_2e$)	Avoided GHGs: Landfilling over 10 years ($MTCO_2e$)	Total GHGs: over 10 years ($MTCO_2e$)	Potential revenues from sales of carbon offset credits (\$ / 10 yrs)[125]
Anaerobic digester (lbs. CO_2/ 10 yrs)	812	-51,824	-51,012	\$1,036,480

Diverting food waste away from landfills is an economically viable and socially palatable way to substantially reduce greenhouse gas emissions. A high level of diversion

[123] The Regional Greenhouse Gas Initiative website is located at: http://www.rggi.org/co2-auctions .
[124] The Western Climate Initiative website is located at: http://www.westernclimateinitiative.org/ .
[125] Based on the current European market price for carbon offset credits (\$20 / $MTCO_2e$) (CCX, 2010).

can be achieved with progressive policies such as the European ban on organics from landfills or mandated organic waste separation such as in the cities of Toronto and San Francisco. In California, CalRecycle recently adopted Strategic Directive 6.1, which calls for 50% diversion of organics from landfills by 2020. Given the potential impact on greenhouse gas emissions and waste disposal, it is possible that this directive could one day become state law.

CHAPTER 11. CONCLUSIONS AND RECOMMENDATIONS

A regional food waste digester could serve as an example of, and living laboratory for, the development of food waste digesters in North America. Information about project permitting, costs, operating parameters, and end products would be available for the purpose of evaluating food waste diversion programs in other communities. The facility itself will serve as a model for the regionalization of waste processing facilities to address the diseconomies of scale often experienced by rural communities. This facility will directly serve Humboldt County by increasing waste diversion from the landfills, generating renewable energy, and reducing the fiscal and environmental costs associated with waste management.

The origins of this project lie in the need for increased landfill diversion. Twenty years after the passage of AB 939,[126] Californians have successfully reached 54% waste diversion from the landfills (CIWMB 2009a). While this achievement speaks to the efficacy of well crafted state and local mandates, the total quantity of waste landfilled continues to grow (CIWMB 2009a).[127] The continued increase in the overall quantity of waste going to landfills indicates that the current waste diversion efforts have merely absorbed the increase in new waste generation. Increasing levels of waste in landfills not only creates increased air and water quality hazards, but it also represents a systemic loss

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[126] CA AB 939 (1989) mandates all California jurisdictions to divert 50% of their solid waste away from landfills.

[127] The increase in total statewide tonnage appears to be primarily driven by increasing population. These data can be seen on the CalRecycle Statewide Per Capita Disposal Rate Statistics page which can be found at: http://www.calrecycle.ca.gov/LGCentral/GoalMeasure/DisposalRate/default.htm . The data show that the per capita disposal rate has decreased over time, yet the population has steadily increased over the same period, increasing the overall waste generated and disposed in California.

of resources and energy.[128] In order to achieve the goals of long-term, sustainable resource use, it is necessary to develop the infrastructure and policies that will enable increased waste diversion from landfills.

Food waste diversion is a tremendous waste reduction opportunity. First, food waste is a large portion of the remaining disposed waste stream and is high in energy content. Second, large scale diversion of food waste will enhance the health of the environment. This waste can be processed to produce soil amendments to return valuable nutrients to the local soils. Diverting food waste will also reduce leachate formation at landfills, and will reduce volatile organic carbon and greenhouse gas emissions in the atmosphere.

Several food waste diversion options were explored during the course of this feasibility study including food banks, pig farms, composting, and anaerobic digestion. The first two of these options were found to be limited in capacity whereas anaerobic digestion and composting were found to be properly scaled for handling large, local volumes of post-consumer food waste. Both processes produce a stabilized soil amendment, but they differ in terms of the energy that is released during waste decomposition. The principal distinction between composting and anaerobic digestion is the ability for anaerobic microorganisms to produce biogas (renewable energy) from decomposing food waste instead of heat. Potential revenues from the sales of renewable energy can be used to reduce project costs. This analysis showed that anaerobic digestion and composting both have a lower lifecycle cost and produce less greenhouse gas

[128] For example, energy and raw materials can be saved by fabricating new products out of recycled materials.

emissions compared to landfilling. The comparison between anaerobic digestion and composting indicates that anaerobic digestion requires less space, less time, and has more control over emissions compared to composting. Although composting has a lower initial investment, the long term operational costs are higher than the costs for operating a digester. This is in large part due to the energy inputs required to run the composting machinery. For these reasons, this feasibility study focuses on the economic viability of establishing a food waste digester facility in Humboldt County.

The main costs associated with developing a food waste digester are the pre-processing equipment and building, the digester, and the workforce required to operate the facility. Revenues from tipping fees, the utilization of the biogas, and the sale of soil amendments can be utilized to balance the annual costs of amortization and operation of the anaerobic digester facility. In the near future, an additional revenue stream may be realized from the sale of carbon emissions offset credits; as California and the United States develop a cap on carbon emissions, this revenue stream will become more valuable.

The economic analysis indicates that food waste collection and digestion at the target scale (10,000 tons / year) would result in a lower lifecycle cost and disposal fee when compared to trucking waste to landfills 380 miles round trip. Additionally, the increasing future cost of waste disposal, as well as the impact of fluctuating fuel prices, can be buffered by the stable cost of a waste management local. Moreover, a regional waste processing infrastructure will benefit Humboldt County jurisdictions as it will enable them to increase or maintain diversion levels and avoid fines associated with AB

939 non-compliance. The participating jurisdictions will be able to collect greenhouse gas reductions credits for all food waste diverted from the landfills. Further, the City of Eureka could save money in the form of reduced demand charges and discounted electricity purchases at the Elk River WWTP.

The Regional Food Waste Digestion Facility is an opportunity for Humboldt County to become a leader in sustainable waste management. Anaerobic digestion of food waste, followed by composting or land application of the digested residual, is a socially and economically feasible way to reduce landfilled waste and greenhouse gas emissions while simultaneously generating renewable energy and improving local top soil. Anaerobic digesters can be located near population centers where the waste is created, and will become more valuable over time as energy prices rise.

Establishing a digester facility will contribute to the long-term sustainability of the regional community. There are few opportunities that address so many needs while simultaneously generating revenues to offset the costs of annual operations. Humboldt County and California have been the leaders in progressive thinking and sustainability for many years. Developing a regional food waste digester facility is yet one more opportunity to further this legacy.

Ancillary Benefits

The following is a list of ancillary benefits in addition to the direct benefits derived from this project.

- **Reduced costs for waste oil collection:**

Fats, oils and grease in the municipal sewer collection lines can cause extensive clogging which increases the operating costs of the wastewater treatment plants. In order to maintain low costs for wastewater treatment services, commercial kitchens are required to have grease traps and grease interceptors to minimize the quantity of FOG entering the collection system. Recently, the California Regional Water Quality Control Board increased grease trap waste collection requirements and indicated that they expect restaurants to increase grease trap and interceptor pumping. This increased collection requirement will result in an added cost of doing business for the commercial sector.

Currently, the pumped waste oil is hauled over 250 miles away to Oakland or Chico, California. More frequent collection will require increased hauling routes between Humboldt county and central California due to the limitations in pumper truck capacity. A local processing facility would allow for more frequent waste oil collection and disposal without substantially increasing quantity of vehicle miles traveled. This reduction can potentially reduce the cost of disposal for commercial businesses, and will help to maintain low quantities of FOG entering into the wastewater collection lines.

- **Job Creation**:

This facility will create new jobs in the waste management sector. Jobs at the facility will be related to the receiving, pre-processing, monitoring and post-processing of organic waste. It is likely that this project will result in additional local waste hauling jobs as well. It is estimated that 4-6 new jobs would be created.

Recommendations for Implementation

The following is a list of recommendations for the development of the regional organic waste processing facility.

- **Develop policy that promotes a relatively clean organic waste stream:**

  The pre-processing required to remove contaminants can be expensive and energy intense. Maintaining low levels of contamination in the organic waste stream is vital for keeping facility operation and maintenance costs to a minimum. Policies and collection programs should be developed to minimize the overall contamination level in the organic waste stream.

- **Scale initial digester equipment to handle larger volumes of waste**:

  This project will inevitably grow and should be sized to handle larger volumes of food waste. Space should be allocated for future digesters to be added on in parallel in order for the project to expand to collect waste from the residential sector.

- **Start with the commercial / industrial sector waste**:

  HWMA and other project developers view the commercial sector as the best opportunity to collect large amounts of food waste with the fewest collection routes. Many commercial generators such as Humboldt State University, College of the Redwoods, and area restaurants have already expressed interest in developing an onsite separation system to divert this waste. Industrial food manufacturing businesses such as Pacific Choice Seafoods, Cypress Grove Chevre, and Humboldt Creamery are also good candidates for initial feedstocks into the digester system. HWMA is currently contacting these commercial entities as part of an organic waste resource assessment. The goal of this assessment is to quantify the organic waste tonnage that can be collected from the large commercial and industrial generators as well as early adopters. Aggregating these sources of organic waste will help the facility to become financially viable.

- **100% availability**:

In order to achieve uninterrupted waste diversion (availability), it is recommended that paired digesters be used. Two digesters connected in parallel can extend the availability and capacity of the digester system. This is due to the ability to shut down one digester for maintenance while the second continues to digest waste.

CHAPTER 12. NEXT STEPS

This opportunity can be realized through a united community effort. The next steps to bring this project to fruition include, but are not limited to, the following:

- **Identify all local organic waste streams:**

  In order to maximize the efficacy of and the revenue streams for the food waste digester, all community organic waste streams should be considered. The list in Appendix J describes only a few of the available waste streams in Humboldt County and Del Norte County. These include fats, oils, grease, glycerin, meat waste, cheese whey, fish waste, and soiled paper. Other local food processing waste streams remain to be identified. All local commercial and industrial generators of food waste should be contacted to ascertain the quantity and characteristics of their digestible waste stream.

- **Permitting**:

  If the Crowley property (owned by the City of Eureka) is to be used, it will need wetlands delineation, a geotechnical analysis, re-zoning, Coastal Development use permits, and potentially, an Environmental Impact Report for CEQA compliance. HWMA is currently working with a local planning firm to complete a CEQA Initial Study document that will identify the potential environmental impacts of the digester facility as well as mitigation measures to address or eliminate these impacts. This work is scheduled to be complete in December of 2010.

- **Solicit Requests for Proposals:**

A request for proposals will enable HWMA and the member agencies to compare commercially available digester systems technologies.

- **Establish regional partners**:

Stakeholders in the Regional Food Waste Digester facility include the HWMA member cities of Humboldt County, development agencies, local enforcement agencies such as the air and water boards, the Coastal Commission, PG&E, the organic waste generators, waste haulers, the composting facility, the CIWMB, and EPA Region 9. Partnerships should be developed with every appropriate stakeholder to enable the project to achieve the maximum waste diversion and greenhouse gas emissions reductions for the lowest cost.

- **Gap funding**:

Funding will be needed for the HWMA staff and project partners to pursue full funding, permitting, develop Requests for Proposals, and pay for a preliminary engineering design. Funds under consideration for these purposes include the Regional Headwaters grant, as well as grant funding from the United States Department of Agriculture, and the U.S. Environmental Protection Agency.

- **Explore Funding Options**:

There are three basic funding mechanisms to support the development of this project: 1) bonds, loans, and/or grants acquired by regional partners, 2) a public-private partnership, and 3) private 3rd party funding.

HWMA was recently approved for $2,000,000 in Federal Clean Renewable Energy Bonds (CREBs). These bonds are known as “tax credit bonds” because the majority of the interest payment on the bond is paid by the Federal government in the form of tax credits to the bondholders. Regardless of the decision to utilize these bonds, HWMA and regional partners will need to acquire other financing such as a local revenue bond measure or private capital funds. Initial exploratory conversations with private firms are ongoing to assess the possibility of a mutually beneficial partnership.

- **Site development**:

The potential site is situated near the Humboldt Bay on bay mud. The use of this site will require Coastal Commission permits, wetlands delineation, grading, pilings, and a storm water runoff treatment plan before any construction can begin. Additional environmental analyses could include archaeological studies, and traffic impact studies.

- **Bench and pilot scale testing**:

Digestion technology has primarily dealt with low-strength wastes such as cow manure and municipal wastewater. Food wastes and fats, oils, and grease are high-strength wastes that require different operating parameters. Bench scale digestion should be done first to determine appropriate mixtures of the different wastes available for processing. The smaller-scale initial digestion serves to characterize the optimal recipe of mixed materials, the optimal loading rate, and to identify operating challenges associated with the different types of waste.

Testing on smaller scales can provide valuable information while minimizing the financial risk of large-scale digester failure.

Testing should begin with the processing of the known organic wastes that will be collected. Lab space at the Arcata WWTP is one possible location suited for this work. Another option is the development of a dedicated lab space on the site itself or at the Eureka WWTP.

- **Program design**:

HWMA and project partners will need to develop a collection program that encourages both participation and a clean organic waste stream. The local hauling to the digester facility will need to be established. Public meetings should be held to address concerns and allow for valuable input. Outreach and education will be essential for developing a critical mass of participation.

Limitations of Study and Future Work

The majority of the existing food waste digestion projects are co-digesting food waste with either manure or municipal sludge. In North America, there are only a few examples of municipal-scale stand-alone food waste digesters, such as the two digesters in Toronto Canada, and the UC Davis pilot project. As these projects are a new application of a proven process, many information gaps exist. This project could fill in some of these gaps and would serve as a model for other communities considering food waste diversion from the landfill. Some of the topics that warrant careful investigation as the project is developed are listed below.

- All digester companies and configurations should be investigated. This includes, but is not limited to, trench style digesters, horizontal systems, batch processing, multi-phase digestion, as well as wet and dry fermentation. Additional consideration should be given to operating the digester at mesophilic versus thermophilic temperatures.
- Experimentation should be performed to determine the following:
  - The optimal combination of disparate organic waste products (i.e., food waste, FOG, fish waste, cheese whey, food-soiled paper, and glycerin) in terms of digestibility, carbon to nitrogen ratio, and pH.
  - Determine which wastes should be combined, and which should be digested separately.
  - Establish the highest organic loading rate, or throughput of organic material, that can be achieved and maintained.
  - Investigate the optimal agitation system for high solids waste including consideration of a non-mixed digester system.
- Contaminant removal from food waste is a relatively new procedure. The equipment on the market is expensive and adds significantly to the parasitic load. Research should be undertaken to assess lower cost options for food waste pre-processing that require minimal energy inputs.
- Further analysis is needed to determine how gas storage and electricity sales during peak periods will affect the economics of the project.

- Finding the best use for the liquid and/or solid fertilizer that will be produced from digested food waste residual will require market research and investigation of the associated regulations.

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APPENDIX A: GROCERY STORE SURVEY

The following table shows the grocery stores that were surveyed by HWMA staff in order to assess their current food waste management practices.

Location	Contact	Meat cuttings	Fat cuttings	Bakery	Pizza / Deli	Vegetables
Costco	Mike Blitken (manager)	resale as ground	rendering	Food Bank	Dispose < 5lbs daily waste	Produce manager didn't have an idea about the quantity of produce being thrown away.
Winco	Diane and Karen (managers)	resale as ground	rendering	Eureka Rescue Mission	Dough ~15lbs daily waste	1st gleaned then thrown away as garbage
Safeway # 641	Amber (manager.)	rendering	rendering	Food Bank	food bank	Sheriff's work alternative program (SWAP) pig farm
Eureka Natural Foods	Rick (owner)	rendering	rendering	n/a	Sheriff's work alternative program (SWAP) pig farm	1st gleaned, then SWAP
Murphy's Market	Randy Walker (manager)	cooked for sale then dispose if not sold.	pigs	Dispose ~10lbs dough/day	food bank	pigs

APPENDIX B: FOOD BANK SURVEY

This table shows the results of the food bank surveys that were conducted by HWMA staff in order to assess their current food waste management practices.

	Organization
FB	Food Bank
SVDP	St Vincent De Paul
ERM	Eureka Rescue Mission
AE	Arcata Endeavor
SA	Salvation Army
MFP	Mckinleyville food pantry
	What kind of food do you accept?
FB	Store gleaning of frozen, canned, packed items and produce.
SVDP	Edible food
ERM	Fresh, frozen, canned-basically all
AE	Gleaned food from stores
SA	Canned, boxed food
MFP	Gleaned food from stores
	Is it important that food be pre or post consumer?
FB	Getting away from post consumer
SVDP	Yes. Pre-consumer only
ERM	Yes. Pre-consumer only
AE	Yes. Pre-consumer only
SA	Yes. Pre-consumer only
MFP	Yes. Pre-consumer only
	What is the criteria for accepting donations?
FB	Has to be fit for human consumption.
SVDP	Inspected for fitness, dates checked, and produce cleaned by staff.
ERM	From stores, private parties through butchers
AE	Food is inspected for fitness and dates checked.
SA	Fit for human consumption, canned or boxed
MFP	Fit for human consumption, from Safeway & Rays

APPENDIX B: FOOD BANK SURVEY CONTINUED

	Organization
FB	Food Bank
SVDP	St Vincent De Paul
ERM	Eureka Rescue Mission
AE	Arcata Endeavor
SA	Salvation Army
MFP	Mckinleyville food pantry
	Do you provide meals or groceries?
FB	Groceries to people and meal providers
SVDP	375-500 meals served daily.
ERM	110,000 meals served yearly.
AE	300-375 meals per week and 75 grocery boxes per week
SA	Groceries to 25-40 households per week
MFP	500 grocery boxes per month
	Are you at capacity for donations?
FB	No
SVDP	No. Always in need.
ERM	No
AE	No.
SA	No. There is always a little need. Their food is purchased usually at the Grocery Outlet
MFP	Always in need of canned goods
	How much food are you throwing away?
FB	Unknown
SVDP	2xweek 45-55ga slop pail
ERM	Minimal prepared food from plate leftovers
AE	7-9 32Ga cans per week
SA	Hardly any food gets wasted
MFP	30-40lbs of bread every week
	Do your food scraps go to pigs or is it disposed as garbage?
FB	Garbage
SVDP	Pigs
ERM	Pigs
AE	Pigs
SA	Garbage
MFP	Garbage

APPENDIX C: PIG FARMER SURVEY

This table shows the results of the survey of pig farmers to assess the local capacity for diverting food waste to pigs.

Pig Farmer	Number of pigs	Slop contributors and contribution quantity			Post consumer food ok?	Notes
Sheriff's Work Alternative Program (SWAP)	37 (9 are newborns)	They receive about three cubic yards daily from various sources	Eureka Rescue Mission: three 25 gal. cans weekly	Eureka Natural Foods & Safeway chain: 1650 gal. barrels per week,	No, all pre consumer Mostly vegetables but no onions, peppers or citrus	Someone is at the pig farm every Sun/Wed/Fri 10 - 2:30
Harold Davison	170+	Ferndale Market: Two to seven 15 gal. boxes, 2x Week	Humboldt Creamery: One pick-up truck load 1x Week Occasional huge loads	Fernbridge Fruit Market (Summer only): One 25 gal. can daily	Yes but labor required to clear contaminants is a concern. Too many contaminants turns pig feed into chicken feed	Not interested in expanding
Joe - quitting pigs to raise goats in a few months	4-6 pigs	St. Vincent De Paul: One 45-55gal. can2x Week			yes, but not preferred	Not interested in expanding
HSU pig farmer	< 8 pigs	Arcata Endeavor: Up to nine 32gal. cans 1x Week			yes, but not preferred	Not interested in expanding
Isidro Homen and Dennis Chizm	up to 8pigs	Mexican Food restaurant: One 30 gal. can 1x Week	Eureka Co-op: Two 55 gal. cans of produce daily		yes, but not preferred	Can handle more produce but nothing else
Justin Martin	2 breeders	Murphy's Market: Two 35 gal. cans 2x Week			No. They use purchased grain or donated vegetables. Looking into using donated bread as well.	This is a new operation and is run by a 16 year old 4H student from McKinleyville.

APPENDIX D: FOOD WASTE COMPOST FACILITY SURVEY

Name of facility:

Location:

Contact Person: Phone:

Date:

1. How much food waste throughput do you have per day (tons/day)?

2. What type of base surface material do you use for composting?

3. What types of materials do you process?

4. What type of composting process do you use?

5. What is your operation and maintenance cost ($/ton)?

6. What were your most significant capital costs?

7. What is your charge per ton for processing food waste ($/ton)?

8. What is your charge per ton for processing green waste ($/ton)?

9. Do you accept material from the residential or commercial sector?

10. What is the food waste to yard waste ratio you use?

11. What is the footprint of your facility? Is it enough?

12. Do you have a method or need for odor control?

13. Do you have a full solid waste permit?

APPENDIX E: FOOD WASTE COMPOST FACILITY SURVEY RESULTS

Facility	Location	Contact	TPD food waste	Base Surface	Material	Type of Composting	Process Costs
Gilton Resource Recovery	Modesto	Dennis (209) 527-3789	300	Compacted road base - dirt that has been worked	100% green waste, does not take food waste anymore - sometimes people bring in a little. Used to accept cleaned, blended f.w.. (w/green waste) from bay area, blend was 60% green 40% food.	windrows	Didn't know
Jepson Prairie Organics 1	Gilroy	Paul Yamamoto (707) 678-1492 ext. 203	100	concrete	Food waste composted separately - using Ag bags - soiled paper and yard waste comingled.	Ag Bags	$40/ton +/1 $5
Jepson Prairie Organics 2	Vacaville		300			Ag Bags	
Jepson Prairie Organics 3	Marysville		50			Ag Bags	
San Joaquin Composting	Lost Hills	Drew Kolowski (800) 746-8404	200	dirt	Food processing waste, biosolids, corndogs. 80% biosolids, 20% liquid fat	windrows	Did not answer
Z-best	Gilroy	Greg Ryan (408) 846-1575	1000	Base Rock	Food waste and green waste	CTI Bags for food waste, windrows for green waste	$20-$25/ton for open windrows, $35-$45/ton for bagged compost
BFI Organics	Milpitas	Mark Buntger (408) 945-2801	800	dirt	10% food waste, 90% green in bags or under cover. After composted, windrows for composting	Windrows	$8-$9/ton
Miramar Greenery	San Diego	Steve Fontana (858) 492-5077	274	dirt over old landfill	Green waste and pre-consumer food waste	windrows	$3.50/ton
California Biomass Inc.	Thermal	Michael Hardy(909) 208-0774	25	clay - no rain impermeable	green waste and food waste	static pile - no aeration, cook for 5-6 months, then windrow for PFRP regulations (130 @ 15 days)	$24.50/ton - $20/ton w/o land lease, elec., loan interest
California Biomass Inc.	Victorville		20		same as above		
Kochergan Farms Composting	Avenal	Eric Kochergan (559) 352-7388	200	dirt	Green waste and residential and commercial food waste	Windrows	"Doesn't keep track of these costs"
Grover Landscape Services	Modesto	Mark Grover	44	compacted dirt	Green waste/ food waste. from Berkeley, SF - they take the capacity that Jepson can't handle. They are contracted (long-term) with Nor Cal	Windrows	$11/ton
Community Recycling & Resource Recovery	Sun Valley	Dave Baldwin (805) 845-4056	1500	compacted clay liner (10-8)	green waste and food waste	windrows	refused to answer

APPENDIX F: FOOD WASTE COLLECTION SCENARIOS

The organic waste quantities listed below are based on assumed capture rates of the available waste streams in the Humboldt County region. See section 10.1 for a description of the scenario assumptions.

Scenario 1 - Low	Tons FW/ year
25% Eureka Commercial food waste	941
25% Arcata Commercial food waste	305
25% Unincorporated County Commercial food waste	463
0% Del Norte food waste	0
100% FOG, Glycerin	1,545
12.5% All Other Incorporated Cities Commercial food waste	163
Total tons per year w/o FOG and Glycerin	1,872
Total tons per year w FOG and Glycerin	3,417
Scenario 2 - Medium	Tons FW/ year
50% Eureka Commercial food waste	1,882
50% Arcata Commercial food waste	609
50% Unincorporated County Commercial food waste	927
75% Del Norte food waste	1,140
100% FOG, Glycerin	1,545
25% All Other Incorporated Cities Commercial food waste	326
Total tons per year w/o FOG, Whey, and Glycerin	4,884
Total tons per year w FOG, Whey, and Glycerin	6,429
Scenario 3 - High	Tons FW/ year
90% Eureka Commercial food waste	3,388
90% Arcata Commercial food waste	1,096
50% Unincorporated County Commercial food waste	927
90% Del Norte food waste	1,368
150% FOG, Glycerin (increased collection)	2,318
75% All Other Incorporated Cities Commercial food waste	978
Total tons per year w/o FOG, Whey, and Glycerin	7,756
Total tons per year w FOG, Whey, and Glycerin	9,360
Scenario 4 – Regional Potential	Tons FW/ year
90%food waste in County	14,458
90% Del Norte Food Waste	1,368
200% FOG, 100% Glycerin, 100% Whey	1,723
Total tons per year w/o FOG, Whey, and Glycerin	15,826
Total tons per year w FOG, Whey, and Glycerin	17,549

APPENDIX G: MAJOR COSTS FOR ANAEROBIC DIGESITON 10,000 TON / YEAR FACILITY

Major costs for digestion facility	Cost per unit ($)	# of units	Total cost	Source
Building ($/ft^2) w/slab	$100	6,400	640,000.00	Dennis DelBiaggio
50' Truck weighing scales	$32,700	1	32,700.00	Scales Unlimited
Foundation for scales inclu. Const.	$20,000	1	20,000.00	Scales Unlimited
Print Kiosk (for weight records)	$4,000	2	8,000.00	Scales Unlimited
Software capable of running reports	$10,000	1	10,000.00	Scales Unlimited
PC computer	$2,000	1	2,000.00	Current PC prices
Card Scanner	$5,000	2	10,000.00	Scales Unlimited
Odor control system	$85,000	1	85,000.00	Bay Products
Bobcat loader	$50,000	1	50,000.00	Estimate
250 KW Cogeneration engine $/kW	$895	250	223,750.00	Martin
Commercial food waste pre-processing equipment ($)	$80,000	1	80,000.00	OEI
Conveyor	$40,000	1	40,000.00	Brown and Caldwell
Metering Pumps	$40,000	3	120,000.00	Brown and Caldwell
Primary Digester ($/gallon)	$5	429,207	1,931,430.00	OEI
Post digestion tank ($/gallon)	$5	429,207	1,931,430.00	OEI
Gas collection equipment	$75,000	1	75,000.00	Canada Composting
H_2S Scrubber Tank	$5,000	1	5,000.00	Sulfa Treat
H_2S scrubber media (Sulfa Treat)	$5,760	1	5,760.00	Sulfa Treat
Monitoring equipment (SCADA)	$100,000	1	100,000.00	BTA quote
Engineering Planning and Design	$250,000	1	250,000.00	Estimate
Permitting	$100,000	1	100,000.00	Estimate
New Full Solid Waste Permit	$6,300	1	6,300.00	Carolyn Hawkins, LEA
Land Preparation ($ /ft^2)	$2	43,560	87,120.00	Estimate
Infrastructure (fencing) ($/linear foot)	$35	1,319	46,170.00	Brown and Caldwell
Infrastructure (roads) ($/ft^2)	$10	6,000	60,000.00	City of Eureka
New Water Service	$110	1	110.00	HBMWD
Access Gates	$10,000	1	10,000.00	Brown and Caldwell
Program Design	$60,000	1	60,000.00	Estimate
Sub total			5,989,770.00	
Balance of systems (contingency)	30% of capital	1	1,796,931.00	Estimate
Total			**7,786,701.00**	

APPENDIX H: ITEMIZED OPERATION AND MAINTENANCE COSTS

The itemized costs listed below are based on labor and insurance costs at the Hawthorne street waste transfer station and the Elk River WWTP. Waste water disposal, gas treatment media and permitting fees were obtained directly from the source. Estimates are included for equipment maintenance and supervisory labor costs.

O&M costs	Cost per unit	# of units	Units	Total annual cost	Source
Labor ($/hour)	$22	120	person hours per week	$140,000.00	CIWMB 2008a, Elk River WWTP, HWMA Operations
Supervision and training ($/hour)	$30	40	person hours per week	$62,000.00	Estimate
Insurance ($/year)	$15,000	1	$/year	$15,000.00	HWMA transfer station insurance - includes liability and property
Iron sponge media replacement ($/year)	4,160	1	$/year	$4,200.00	Sulfa treat
Equipment maintenance (2% of equipment costs)	2%	$5,460,270	$/year	110,000.00	Estimate
Solids management ($/ton)	41	912	$/ton	$37,000.00	Processing cost at HWMA compost facility
New Wastewater disposal permit fee (good for first 3 years)	450	1	$/3years	$150.00	Justin Boyes - Pretreatment coordinator at Elk River WWTP
Waste water disposal permit fee (not new)	250	1	$/3 years	$83.00	Justin Boyes - Pretreatment coordinator Elk River WWTP
Solid waste permit annual inspection fee	3,788	1	$/year	$3,800.00	Carolyn Hawkins, LEA
		Total: $/year		$370,000.00	
		$/ton O&M		$37.00	

APPENDIX I: CPUC FEED-IN TARIFF FOR SMALL RENEWABLE ENERGY GENERATION[129]

Approved in 2006, California Assembly Bill 1969 requires all utilities to file with the California Public Utilities Commission (CPUC) a feed-in tariff to provide for payment for every kWh of renewable energy produced at a public water or wastewater treatment plant that is a retail customer of the utility. PG&E extended this feed-in tariff to include all other customers who install renewable energy generation equipment up to 1.5 MW in capacity. CPUC Code Section 399.12 defines renewable generation as an in-state facility using biomass, solar thermal, photovoltaic, wind, geothermal, fuel cells using renewable fuels, small hydroelectric generation of 30 megawatts or less, digester gas, municipal solid waste conversion, landfill gas, ocean wave, ocean thermal, or tidal current.

There is a state-wide cap of 250MW divided amongst the utilities proportionately (based on the ratio of the utility's peak demand to the state-wide demand). This means that the utilities are required to offer these rates to water and wastewater treatment plants (WWTP) until the 250MW state wide level is reached. For non-waste water treatment plants, the utilities can offer voluntarily an expansion of the tariffs limited to 228MW state-wide. The state wide limit for both sets of tariffs is therefore limited to 478MW. Once the state-wide cap is reached, no new contracts will be offered under current rules.

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[129] This summary is based on the information available on the PG&E website located at: http://www.pge.com/b2b/energysupply/wholesaleelectricsuppliersolicitation/standardcontractsforpurchase/ .

Feed-in tariffs are based on the Market Price Referent (MPR) determined by the CPUC. The MPR "represents the cost of a long term contract with a combined cycle gas turbine facility, levelized to a cent-per-kilowatt hour value" (CPUC, 2008). The MPR is determined periodically in the renewable portfolio standard proceeding. An eligible facility must enter into a long term contract with the utility for 10, 15, or 20 year increments. The MPR varies by the length of contract selected and the year that the contract is signed.

Each utility has its unique rate structure based on the MPR and a utility-generated multiplier. For example, at the time of this writing, the on-peak rate for PG&E is 2.03 multiplied by the base rate of $0.11126 / kWh resulting is a price of ~$0.23 / kWh during the months of June through September during the hours of 12 to 8 pm. Off peak rates are as low as $0.07 / kWh

Electrical interconnection is through PG&E's Small Generator Interconnection Procedures (SGIP) as filed and approved by the Federal Energy Regulatory Commission (FERC). For the Eureka WWTP, see standard contracts # 3098EB and #3100EB. See the CPUC decision # 0707027 for more detailed information.

APPENDIX J: MAJOR COSTS FOR IN-VESSEL COMPOSTING 10,000 TON / YEAR FACILITY

This table shows the major costs for developing an in-vessel composting facility. The capital cost is the average capital cost from the HWMA RFI responses. Some equipment varies depending on the available feedstocks and technology chosen, for this reason the total does not include all equipment shown.

Major costs for in vessel compost facility	Cost per unit ($)	# of units	Total cost	Source
Building ($/ft^2) w/slab	$100	6,400	$640,000	Dennis DelBiaggio
50' Truck weighing scales	$32,700	1	$32,700	Scales Unlimited
Foundation for scales w/ Const.	$20,000	1	$20,000	Scales Unlimited
Print Kiosk (for weight records)	$4,000	2	$8,000	Scales Unlimited
Software capable of running reports	$10,000	1	$10,000	Scales Unlimited
PC computer	$2,000	1	$2,000	Current PC prices
Card Scanner	$5,000	2	$10,000	Scales Unlimited
Odor control system	$85,000	1	$85,000	Bay Products
Grinder	$165,000	1	$165,000	RFI
Compost turner or front-end loader	$118,000	1	$118,000	Caterpillar
Trommel screen	$110,000	1	$110,000	Wildcat Trommel
Mixer	$59,000	1	$59,000	RFI
Compost Control system	$25,000	1	$25,000	RFI
Biofilter media	$50,000	1	$50,000	RFI
Average cost of In-vessel system on market	$2,819,879	1	$2,819,879	RFI
Engineering Planning and Design	$250,000	1	$250,000	Estimate
Land Preparation ($/2 acres)	$30,000	2	$60,000	Estimate
Infrastructure (fencing) ($/linear foot)	$35	1,319	$46,165	Brown and Caldwell
Infrastructure (roads) ($/ft^2)	$12	6,000	$72,000	City of Eureka
New Water Service	$110	1	$110	HBMWD
Access Gates	$10,000	2	$20,000	Brown and Caldwell
Permitting	$100,000	1	$100,000	Estimate
New Full Solid Waste Permit	$6,300	1	$6,300	Carolyn Hawkins LEA
Program Design	$60,000	1	$60,000	Estimate
Sub total			$4,592,454	
Balance of systems (contingency)	30% of total capital	1	$1,377,736	Estimate
Total			**$5,970,190**	

APPENDIX K: LIFE CYCLE COST
IN-VESSEL COMPOSTING

The lifecycle cost analysis for in-vessel composting is based on 10 responses to a Request for Information (RFI) for a 10,000 ton / year in-vessel composting system solicited by HWMA. To calculate the Life cycle cost (LCC) of an in-vessel composting system, I used the average capital and operation and maintenance costs as well as average energy use values provided in the RFI. This analysis assumes a diesel fuel cost of $3.00/gallon, and $0.12 / kWh for electricity. Replacement equipment costs and lifecycles were also provided in the RFI. Not all system components are included in this LCC analysis due to the variation between technology approaches. For example, bagged in-vessel systems require replacement covers every 5 years while concrete trench systems do not.

The annual O&M and fuel costs increase the LCC of in-vessel composting over time because they are recurring annual expenses. The equations used in this analysis can be seen in the Methods section (Chapter 8). The term "PV" refers to the present value of a future one-time cost. The term "UPV" refers to the present value of a uniformly distributed cost over time (i.e., an annual revenue stream, or an annual payment on a loan). The overall LCC is the sum of all the one-time and recurring costs and revenues over a chosen time horizon (in this case, 20 years).

Item	**cost ($)**	**Year**	**Present value equation**	**Present value**
Capital cost	$5,970,190	0	PV	$5,970,190
Operation and maintenance	$512,818	1 through 20	UPV	$6,390,846
Electricity charges	$55,901	1 through 20	UPV	$696,656
Fuel charges	$49,525	1 through 20	UPV	$617,188
Replacement equipment				
Grinder	$165,000	15	PV	$79,368
Loader	$118,000	10	PV	$72,442
Screen	$110,000	12	PV	$61,252
Blowers (10* $2,000ea)	$20,000	5,10,15,20	PV	$11,137
Temperature Probes	$2,000	5,10,15,20	PV	$4,511
Compost control system	$2,000	10	PV	$15,348
Scale	$32,700	15	PV	$52,912
			LCC	**$14,024,760**
			$/ton over life cycle	**$70**

APPENDIX L: LIFECYCLE COST ANAEROBIC DIGESTION SYSTEM

The Life cycle cost (LCC) of the anaerobic digestion system is based on the equipment costs and renewable energy generation potential evaluated in this analysis. The major costs that were factored into this analysis can be seen in Appendix G. The estimated annual operation and maintenance costs can be seen in Appendix H, and methods for estimating the renewable energy generation potential (and associated revenue streams) can be seen in the Methods section (Chapter 8). The LCC analysis shows that the annual revenue streams from renewable energy sales help to keep the cost of the anaerobic digestion system low over time. The values shown in red are revenues.

The equations behind these results can be seen in the Methods section (Chapter 8). The term "PV" refers to the present value of a future one-time cost. The term "UPV" refers to the present value of a uniformly distributed cost over time (i.e., an annual revenue stream, or an annual payment on a loan). The overall LCC is the sum of all the one-time and recurring costs and revenues over a chosen time horizon (in this case, 20 years).

Item	**Cost ($)**	**Year**	**Present value equation**	**Present value ($)**
Capital cost	$7,786,702	1	PV	$7,786,702
Operation and maintenance	$340,000	1 through 20	UPV	$4,237,152
Electricity	$197,817	1 through 20	UPV	$2,465,236
Offset Natural gas	$1,773	1 through 20	UPV	$22,090
Fuel	$24,000	1 through 20	UPV	$299,093
Tipping fees for other organics	$32,838	1 through 20	UPV	$409,237
Replacement equipment				
Small Loader	$50,000	10	PV	$30,696
Scale	$32,000	15	PV	$15,729
		LCC		$9,472,809
		$/ton over 20 years		**$47**

APPENDIX M: LIFE CYCLE COST
BUSINESS-AS-USUAL (80,000 TONS / YEAR)

The lifecycle cost for continuing to haul waste to landfills is based on the terms of HWMA's hauling contract, the 20 year average fuel escalation rate, a landfill tipping fee o f $24 / ton and the Hawthorne street transfer station tipping fee of $38.37 / ton. See the Methods section (Chapter 8) for the equations that generated the results below.

Fuel escalation rate increases at same rate as 20 yr average (2.5%)					
Year	**Total hauling charge adjusted for increasing fuel prices and inflation ($/trip)**	**Total hauling charge ($/ton)**	**Total cost per ton including landfill tipping fee and Hawthorne St. process fee ($/ton)**	**Annual cost of waste hauling ($/year)**	**Present value of waste hauling ($/year)**
0	$695	33	95	$7,637,299	$7,637,299
1	$710	34	97	$7,783,420	$7,412,781
2	$725	35	99	$7,932,581	$7,195,085
3	$741	35	101	$8,084,850	$6,983,997
4	$757	36	103	$8,240,296	$6,779,312
5	$773	37	105	$8,398,989	$6,580,828
6	$790	38	107	$8,561,003	$6,388,352
7	$807	38	109	$8,726,411	$6,201,697
8	$824	39	111	$8,895,289	$6,020,682
9	$842	40	113	$9,067,715	$5,845,130
10	$860	41	116	$9,243,768	$5,674,872
11	$879	42	118	$9,423,529	$5,509,742
12	$898	43	120	$9,607,082	$5,349,583
13	$917	44	122	$9,794,512	$5,194,239
14	$937	45	125	$9,985,906	$5,043,561
15	$957	46	127	$10,181,352	$4,897,404
16	$978	47	130	$10,380,943	$4,755,630
17	$999	48	132	$10,584,772	$4,618,101
18	$1,021	49	135	$10,792,934	$4,484,687
19	$1,043	50	138	$11,005,528	$4,355,261
20	$1,066	51	140	$11,222,653	$4,229,700
	Total cost over 20 years			**$184,328,178**	
			LCC 20 years		**$116,928,242**

APPENDIX N: 50% CALIFORNIA FOOD WASTE DIVERSION GHG REDUCTION POTENTIAL UNDER CHICAGO CLIMATE EXCHANGE PROTOCOL

GHG Reductions if 50% of California's Food Waste is Diverted Annually Under the Chicago Climate Exchange Protocol											
Initial year tons diverted	**Tons / year diverted**	**MTCO$_2$e/Year Eligible for Crediting**									
		Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Year 1	2,793,292	712,290	589,385	486,033	100,559	83,799	69,832	55,866	47,486	39,106	33,520
Year 2	2,793,292		712,290	589,385	486,033	100,559	83,799	69,832	55,866	47,486	39,106
Year 3	2,793,292			712,290	589,385	486,033	100,559	83,799	69,832	55,866	47,486
Year 4	2,793,292				712,290	589,385	486,033	100,559	83,799	69,832	55,866
Year 5	2,793,292					712,290	589,385	486,033	100,559	83,799	69,832
Year 6	2,793,292						712,290	589,385	486,033	100,559	83,799
Year 7	2,793,292							712,290	589,385	486,033	100,559
Year 8	2,793,292								712,290	589,385	486,033
Year 9	2,793,292									712,290	589,385
Year 10	2,793,292										712,290
Year 11	2,793,292										
Year 12	2,793,292										
Year 13	2,793,292										
Year 14	2,793,292										
Year 15	2,793,292										
Year 16	2,793,292										
Year 17	2,793,292										
Year 18	2,793,292										
Year 19	2,793,292										
Year 20	2,793,292										
Total		712,290	1,301,674	1,787,707	1,888,266	1,972,064	2,041,897	2,097,763	2,145,249	2,184,355	2,217,874
Total									**10 year total**		**18,349,138**

APPENDIX O: 50% CALIFORNIA FOOD WASTE DIVERSION GHG REDUCTION POTENTIAL UNDER CLIMATE ACTION RESERVE PROTOCOL

GHG Reductions if 50% of California's Food Waste is Diverted Annually Under Climate Action Reserve protocol											
Initial year tons diverted	**Tons / year diverted**	**$MTCO_2e$/year eligible for crediting**									
		Year 1	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 6**	**Year 7**	**Year 8**	**Year 9**	**Year 10**
Year 1	2,793,292	615,670	511,686	425,264	88,360	73,436	61,033	50,725	42,158	35,037	29,120
Year 2	2,793,292		615,670	511,686	425,264	88,360	73,436	61,033	50,725	42,158	35,037
Year 3	2,793,292			615,670	511,686	425,264	88,360	73,436	61,033	50,725	42,158
Year 4	2,793,292				615,670	511,686	425,264	88,360	73,436	61,033	50,725
Year 5	2,793,292					615,670	511,686	425,264	88,360	73,436	61,033
Year 6	2,793,292						615,670	511,686	425,264	88,360	73,436
Year 7	2,793,292							615,670	511,686	425,264	88,360
Year 8	2,793,292								615,670	511,686	425,264
Year 9	2,793,292									615,670	511,686
Year 10	2,793,292										615,670
Year 11	2,793,292										
Year 12	2,793,292										
Year 13	2,793,292										
Year 14	2,793,292										
Year 15	2,793,292										
Year 16	2,793,292										
Year 17	2,793,292										
Year 18	2,793,292										
Year 19	2,793,292										
Year 20	2,793,292										
Total		615,670	1,127,356	1,552,620	1,640,980	1,714,416	1,775,449	1,826,174	1,868,332	1,903,369	1,932,489
Total									**10 year total**		**15,956,856**

APPENDIX P: SOURCES OF ORGANIC WASTE IN ADDITION TO FOOD WASTE

Anaerobic digesters can be used to process other commercial and industrial organic waste streams. The following is a list of identified waste streams in Humboldt County that can be included as additional feedstocks for the Humboldt regional food waste digester facility. The addition of these other feedstocks will increase the biogas production and improve the economics of the system.

Food Soiled Paper

Food-soiled paper is not accepted by recycling centers as it is contaminated and cannot be used for processing into new paper. This waste can be aerobically composted; however, it is considered to be food waste by CalRecycle and cannot be composted at facilities not permitted to accept food waste. Anaerobically digesting food soiled paper will increase the diversion potential. Further, processing soiled paper will generate data on the quantity of this waste that can be added to the feedstock mix, as well as information about operational considerations.

Grease Trap Waste from Footprint Recycling

Grease from the drains of commercial kitchens is intercepted in grease traps and grease interceptors as required by the local sewer/water districts. Grease traps are required to reduce the clogging and maintenance of sewer lines. Footprint Recycling, a local bio-diesel manufacturer, collects the dirtier waste oils in order to maintain contracts to collect the cleaner yellow grease that is used to make bio-diesel. The grease trap waste is approximately 70% water and is lower quality grease as it can be contaminated with soaps, hair and food residues. Footprint Recycling hauls this waste to central California in pumper trucks and pays $0.15/gallon to dispose of it (Cooper, 2008). This waste product can be de-watered and added to the digesters for additional gas production. About 200,000 – 300,000 gallons per year are available from Footprint Recycling (Cooper, 2008). Additional volumes of waste oil may be collected from other waste oil haulers operating in Humboldt County.[130] Collecting grease trap waste and processing it locally will enable more frequent waste oil pumping and can reduce the cost of disposal by avoiding long distance hauling. Further, frequent waste oil pumping will result in less fats, oils, and grease entering the wastewater collection lines which will help to keep maintenance costs low at the local WWTP.

Glycerin from footprint recycling

Glycerin is a by-product of the bio-diesel manufacturing process. Glycerin is a carbohydrate – essentially all carbon, hydrogen, and oxygen with very little nitrogen. This glycerin would need to be mixed with another substrate to reach an optimal carbon-to-nitrogen ratio (C:N) suitable for digestion. In a 2007 U.C. Davis study, both glycerin and a mixture of glycerin and dairy manure were tested to determine the digestibility of these feed stocks. Researchers found that the mixture of glycerin and dairy manure to be a feasible substrate mix for digestion (Zhang et al., 2007a). The mixture of nitrogen-rich manure (C:N 9:1) balances out the carbon-rich glycerin (C:N 274.9) (Zhang et al.,

[130] All grease trap and interceptor waste is currently hauled to central California, regardless of which company collects the waste.

2007a). In the study, the glycerin was found to be highly digestible, but caused some inhibition, or reduction of microbial activity, for mixtures with higher levels of glycerin and lower levels of manure. According to Footprint Recycling, 10,000 to 20,000 gallons of glycerin per year are available for digestion (Cooper, 2008). This quantity of glycerin is 1% - 3% of the expected food waste collection volumes.

Meat scraps

Local commercial meat scraps are hauled to a rendering facility in Sacramento and disposed of at a cost of $0.07/lb + hauling costs. An estimated 32,000 lbs per year of meat scraps are available for digestion (Cooper, 2008). Additional permitting and processing steps may be necessary.

Whey

Whey is the liquid part of milk that remains after the milk is curdled in the cheese making process. Cypress Grove Chevre, a local goat cheese manufacturer, currently discharges a portion of its whey into the wastewater treatment system and land applies the remainder of the whey on a parcel of property adjacent to the facility. Due to limitations on the quantity of whey that can be discharged annually, an opportunity exists to digest whey from the facility. Whey is an acidic waste with a pH of 4 that needs to be neutralized with the addition of a base. Cypress Grove currently has over 1,000 tons per year of whey that could be processed in the Regional Food Waste Digester facility (Cypress Grove Chevre, 2008). Additional sources of whey may be available from other cheese manufacturing operations in the county.

Fish processing waste

According to Rick Harris, General Manager of Pacific Choice Seafoods, approximately 90% of their waste stream is organic waste. Additionally, Pacific Choice collects residual proteins and fats from their waste water treatment. Fish and shrimp processing waste would provide another source of high energy content organic waste for the digester system.

Food waste from Del Norte County

The Del Norte Solid Waste Management Authority (DNSWMA) recently put out a request for proposals for processing 1,400 tons per year of food waste as well as other waste products. The Del Norte Solid Waste Management Authority and Hambro, the waste collection company contracted by Crescent City, are interested in hauling food waste from Del Norte to a regional facility in Humboldt County. Hambro is investigating the possibility of back-hauling the digested residual as a feedstock for their compost facility. HWMA, DNSWMA and Hambro are continuing to discuss the possible arrangements for digesting this source of food waste.