ANAEROBIC DIGESTION EVALUATION STUDY

Prepared for the Partnership on Waste and Energy

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Executive Summary

The Partnership on Waste and Energy (PWE) is a partnership between Minnesota's Hennepin, Ramsey, and Washington counties focused on policy development, emerging waste processing technologies, communications, and energy issues. In response to a 75 percent recycling goal passed by the Minnesota Legislature, counties in the Twin Cities metro area are considering new strategies for increasing the percentage of waste that is recycled. PWE has identified anaerobic digestion (AD) technologies as a potentially viable strategy to process source-separated and mechanically separated organics produce clean renewable energy, and help achieve the 75 percent recycling goal.

PWE commissioned the Great Plains Institute (GPI) to review how the technology has worked in other locations and to evaluate the primary economic factors that contribute to the financial feasibility of an AD operation in the Twin Cities metro area. GPI conducted a review of the literature regarding AD technologies, convened a task force of interested parties and AD experts, conducted elicitation interviews with individual AD experts to better understand capital and operating costs, and conducted economic modeling for multiple project scenarios.

AD is a widely used technology in North America and Europe for processing a variety of organic wastes, including the organic fraction of municipal solid waste (MSW). The process employs specialized bacteria to break down organic waste in an oxygen-depleted environment to produce biogas and an organic residue called digestate. Biogas is a mixture of methane, carbon dioxide, other gases, and water. It can be combusted as-is for heat and electricity or cleaned and compressed to be used as a vehicle fuel or as a substitute for natural gas. Digestate is a fibrous solid/sludge that can be used in the same way as compost for soil improvement.

Based on the literature review and input from the Anaerobic Digestion Task Force convened for this report, many types of digestion systems would be suitable for processing organics in the Twin Cities metro area. The AD industry is well developed in the United States (US), although there are relatively few stand-alone digestors processing the organic fraction of MSW. MSW AD projects are well established in Europe.

Key takeaways following the literature review and AD Task Force meetings include:

- There are 244 active AD facilities in Europe processing the organic fraction of solid waste, which is enough to process 5 percent of that material produced in Europe.
- There is no clear technology winner in Europe, with a variety of systems being deployed commercially (e.g., mechanically vs. source separated, mesophilic vs. thermophilic, etc.)
- Europe's AD market is driven in part by policies not present in the US; in particular, high electricity prices for renewable electricity driven by feed-in tariffs.

- Although AD technology is established in the US (over 1,500 projects estimated), there are relatively few stand-alone projects that primarily use the organic fraction of MSW. One study found that 154 projects in the US process food waste, but many of them are wastewater treatment or on-farm systems that co-digest food waste. Of the 61 stand-alone systems, many are food processing facilities (like breweries, dairies, potato processing plants, etc.).
- Nevertheless, there are several notable stand-alone AD projects in the US that focus on MSW, several of which are described in the case studies section in this report. Co-digestion of food waste at on-farm and wastewater treatment AD plants is widespread. Additionally, we identified two notable AD projects in Surrey, British Columbia and Toronto, Ontario in Canada using the organic fraction of solid waste. Drivers for increased AD of municipal waste are similar in Canada and the US.
- US food waste AD facilities primarily produce heat, electricity, or both. Only seven facilities compressed biogas for use in vehicles, and two processed renewable natural gas for pipeline injection.
- A successful project in the US is a hybrid that draws from state-of-the-art operational and technological experience in Europe (and might use European technology, although there are also US vendors), but bases its revenue model on US policy and economic realities.

GPI's economic modeling was conducted to evaluate the financial feasibility of potential AD projects in the Twin Cities metro area. For this study, a range of processing volume scenarios were designed to assess economic performance at varying levels of biogas production and market prices for the final bioenergy product. Three primary uses for AD derived biogas were considered: onsite electric generation, partial upgrading and compression to compressed natural gas (CNG) for transportation vehicles, and pipeline-quality upgrading for sale to the California Low Carbon Fuel Standard (LCFS) market.

Key takeaways from the economic modeling include:

- The highest revenues for the project come from a combination of higher tipping fees and policy revenue from the federal Renewable Fuel Standard and the California LCFS.
- There are economies of scale with AD projects, and larger-scale projects are more profitable and less likely to operate at a loss.
- There were multiple scenarios that resulted in a profitable project.
- Replacement of diesel fuel with renewable natural gas (RNG) had the greatest greenhouse gas benefit.

Biogas is expected to displace the use of conventional fuels in each scenario, resulting in significant reductions of greenhouse gas emissions. Scenarios detailed in this report suggest that an AD project in the Twin Cities metro area would be economically viable.

Considering the environmental and economic benefits of deploying AD technologies, GPI recommends that PWE takes the next steps for stakeholder engagement designed to garner support for an AD project that contributes to meeting the state's recycling goals and reduces greenhouse gas emissions.

Looking ahead, there are several things GPI has identified as next steps:

- Further exploration of the potential for revenue from digestate, or cost of disposal, is needed.
- Further exploration of the technology and processes for assuring good odor control is needed.
- The counties should explore the formation of strategic partnerships for additional feedstock supply and with electric and natural gas utilities for sale of biogas.
- There should be a process to identify the appropriate technology given the likely feedstock supply, and the project must assure a reliable and consistent supply of feedstock to have a viable project.
- GPI will lead a stakeholder process in the coming months to engage additional stakeholders and develop recommendations for public policy and regulations.

History

The Partnership on Waste and Energy (PWE) is a partnership between Minnesota's Hennepin, Ramsey, and Washington counties created to assist the counties in accomplishing their waste management and energy goals. PWE focuses on policy development, emerging waste processing technologies, communications, and energy issues. In Minnesota, counties are responsible for managing waste, following county solid waste plans that are consistent with a regional plan developed by the Minnesota Pollution Control Agency and the state's waste management hierarchy. The counties manage waste to reduce environmental, public health, and financial risk.

Responding to a new 75 percent recycling goal passed by the legislature, counties in the Twin Cities metro area are considering new strategies for increasing the percentage of waste that is recycled and reducing the percentage of waste entering landfills. PWE is evaluating the potential for anaerobic digestion (AD) technology to play a role in processing the organic fraction of municipal solid waste (MSW) and achieving the 75 percent recycling goal.

The counties are considering a variety of strategies that could produce energy and other products from waste materials. AD is a widely used technology in North America and Europe for processing organic waste in an oxygen-controlled environment to produce biogas and digestate. Biogas is a combustible gas composed of methane, carbon dioxide (CO_2), and other components that can be combusted for heat or electricity generation, upgraded for use as a vehicle fuel or a natural gas substitute directly integrated into the natural gas network, or used to synthesize renewable chemicals. Digestate is a solid or liquid material that can be land applied or further processed to produce concentrated nutrient products.

AD is a fully commercial technology and has been used to process a wide variety of organic materials including food waste, wastewater treatment residues, animal manure, a wide variety of food processing wastes, and the organic fraction of MSW. There are numerous types of AD systems, technology vendors, operations at various scales, and production of a wide variety of energy and non-energy products. Selecting the right AD system depends on the type of waste being processed, the size of the system, the intended market served, and the policy and regulatory environment.

Policy incentives are often a driver of an economically successful project. Many jurisdictions have policies in place to create incentives for certain potential products from AD systems, which influence the design of the project. For example, many European countries have generous subsidies for producing electricity from biogas, which create incentives for AD systems to produce renewable electricity. In the US, there has been a recent focus on AD systems producing upgraded renewable natural gas for transportation fuel, partly due to incentives through the federal Renewable Fuel Standard (RFS) and the California Low Carbon Fuel Standard (LCFS).

AD is in widespread use in the US and the European Union (EU) but remains a small part of the overall energy system in the US today. The Nicholas Institute of Environmental Studies at Duke University evaluated the overall market potential of biogas in the US. They estimated that there is a sufficient biogas resource in the US to potentially displace 3 to 5 percent of natural gas use as a cost of $5-6/MMBtu and up to 30 percent at higher biogas prices. These are higher than current gas prices in the Twin Cities metro area which have ranged from $2-4 per MMBtu over the past two years. Two percent of natural gas in the EU is already sourced from biogas.[2]

This study is not the first attempt in the Twin Cities metro area to evaluate the potential for AD technology. In a 2013 report to the Ramsey Washington County Resource Recovery Project, Foth Infrastructure & Environment, LLC (Foth), evaluated a variety of technology alternatives for processing MSW. The researchers found AD to be a proven technology in North America, suitable for processing the organic portion of solid waste. Furthermore, they found that reliable cost data exists, that an AD project should be permittable, and that it could be integrated into a system with other process technologies such as gasification for processing other portions of the waste supply.[3] Additionally, the report included a review of AD technologies suitable for solid waste, a list of potential technology vendors, and a list of case studies.

In 2018, Hennepin County commissioned a study with the University of Wisconsin – Oshkosh to evaluate the characteristics and biogas potential of feedstocks from the county. The study included pilot-scale production in liquid and dry digestors to evaluate the type of system that fits the waste profile as well as a full-scale trial in a dry batch system. The researchers evaluated six representative feedstocks that were components of solid waste in the county and found that all were suitable candidates for digestion and yielded good quality biogas. The study did not recommend a specific system type, finding that several pathways exist.

Ramsey, Washington, and Hennepin counties have taken steps in considering anaerobic digestion for managing their waste. Hennepin County's 2018 Solid Waste Management Master Plan, adopted by the County Board in 2017, includes strategies aimed at recycling 75 percent of the county's trash and achieving zero waste to landfills by 2030. This would be accomplished by preventing waste and capturing maximum value from recovered materials, which can include capturing biogas from organics. Hennepin County released a Request for Qualifications in 2018 seeking "submissions from

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[2] Murray, Brian C, Christopher S Galik, and Tibor Vegh. 2014. "Biogas in the United States: An Assessment of Market Potential in a Carbon-Constrained Future." *Rep. Biogas in the United States: An Assessment of Market Potential in a Carbon-Constrained Future.* Duke Nicholas Institute for Environmental Policy Solutions. https://nicholasinstitute.duke.edu/sites/default/files/publications/ni_r_14-02_full_pdf.pdf.
[3] Foth Infrastructure & Environment, LLC. 2013. "Alternative Technologies for Municipal Solid Waste." *Rep. Alternative Technologies for Municipal Solid Waste.* Lake Elmo, MN: Foth Infrastructure & Environment, LLC.

qualified, experienced, and financially capable entities that can verifiably demonstrate the ability to anaerobically digest a minimum of 25,000 tons per year of source-separated organics in an economically and environmentally sound manner to produce energy and beneficial soil or agricultural supplements."[4]

In addition to the 2013 Foth study evaluating technology alternatives, Ramsey and Washington counties have also taken significant steps toward a new approach to managing their waste. Ramsey and Washington counties formed a joint powers board—the Ramsey Washington Recycling and Energy Board—to take over operation of the Recycling and Energy Center (formerly the Newport Refuse Derived Fuel plant). A guiding principle of the board is to pivot from viewing trash as a "waste" and increasingly view it as a "resource" that adds value to the environment and the economy. The board is moving forward with plans to increase source separation and reuse and increase mechanical separation of recyclables and organics. Their work to date indicates that anaerobic digestion is a suitable technology for municipal solid waste, that it is a fully commercial technology, that it helps the counties achieve their 75 percent recycling goal, and that it has the potential to offer environmental, health, and economic advantages.

This study is intended to build upon previous work by the counties by offering an overview on the environmental, economic, energy, regulatory, and policy considerations related to potentially building and operating one or more anaerobic digestion projects within the three counties. It is also intended to provide a base level of information to allow for engagement with stakeholders whose input will be crucial in a successful project.

[4] "Request for Qualifications: Anaerobic Digestion of Organic Materials." n.d. Hennepin County, Minnesota. Hennepin County, Minnesota. Accessed September 25, 2018. https://www.hennepin.us/business/work-with-henn-co/rfq-anaerobic-digestion-organic-materials.

Project Overview

The Great Plains Institute's (GPI) scope of work includes a report and a stakeholder engagement process. For this report, we have gathered information in four ways:

- Literature review: we have reviewed relevant literature on anaerobic digestion, focusing on technologies and projects suitable for municipal solid waste.
- Anaerobic Digestion Task Force: we organized and facilitated two meetings of an Anaerobic Digestion Task Force, engaging anaerobic digestion experts from around the Twin Cities metro area.
- Elicitation interviews: we conducted elicitation interviews to gather information on the capital and operating costs of anaerobic digestion systems, resulting in around 20 individual data points.
- Economic modeling: combining information from the literature review with input from the task force and individual interviews, GPI constructed a new economic model for evaluating the financial performance of a potential anaerobic digestion system and conducted sensitivity analysis for key variables related to cost and revenue. Results from this model are presented in this report, and the model will be available for the counties for evaluating additional scenarios.

GPI will present a final report to the Partnership on Waste and Energy on September 27. Following the presentation of the report, GPI will lead a stakeholder engagement effort to gather feedback on the level of support for new anaerobic digestion projects and build consensus on next steps for the region and potential policy and regulatory changes necessary to make a project a reality.

Anaerobic Digestion Technology

Anaerobic digestion (AD) is a process that employs specialized bacteria to break down organic waste in an oxygen-depleted environment. It produces an organic residue called digestate, and a gas known as biogas. Biogas is a mixture of methane, carbon dioxide (CO_2), and water. It can be combusted as-is for heat and electricity or scrubbed and marketed as a substitute for natural gas. Digestate is a fibrous solid/sludge. It can be used in the same way as compost as a soil improver, or it can be composted after AD to increase the breakdown of lignin and cellulose.

Anaerobic digestion is a staged process. The stages are as follows:

- Hydrolysis: breakdown of complex insoluble organic matter into simple sugars, fatty acids, and amino acid.
- Acidogenesis: further breakdown of simple sugars, fatty acids, and amino acids into alcohols & volatile fatty acids (VFAs).
- Acetogenesis: conversion of VFAs and alcohols into acetic acid, CO_2, and hydrogen.
- Methanogenesis: acetic acid and hydrogen are converted into methane and CO_2 by methanogenic bacteria.

A wide variety of organic feedstocks have been used for anaerobic digestion. Feedstocks are normally organic wastes (such as the organic fraction of municipal solid waste [MSW], food waste, animal manure, etc.), but purpose-grown energy crops have also been used (for example, corn silage in Germany grown exclusively for energy production via AD). Common sources include municipal, commercial, and industrial food wastes, agricultural wastes (e.g., slurries, poultry litter, and manure), wastewater and sludges from industrial waste treatment, food/beverage processing waste, and energy crops (e.g., maize, grass, and silage).

There are numerous factors to consider in evaluating the type of feedstock available to design an anaerobic digestion system including source, composition, contaminants, storage system, and seasonal fluctuation.

Selection of an appropriate AD technology depends on many variables, with the type and composition of feedstock representing a major factor.

- Wet vs. dry
- Digestion process flow: batch vs. continuous flow
- Digestion process stages: single-stage vs. multi-stage
- Operating temperature: thermophilic vs. mesophilic

In its 2013 report, Foth offers a detailed overview of AD process technologies and technology vendors. Based on a literature review and input from the Anaerobic Digestion Task Force, that many types of digestion systems would be suitable for an MSW AD system in the Twin Cities. Hennepin County will gather initial input through its request for qualifications process, and Ramsey Washington Recycling and Energy Board are exploring more detailed project design considerations. Recommending a specific AD technology is beyond the scope of this project.

STATUS IN EUROPE

AD has proved to be a viable option for waste management in several European countries and is in widespread use. Europe currently has about 244 active facilities with a cumulative capacity of 7,750,000 tons per year that process the organic fraction of MSW as a significant part of their feedstock, which is enough to process five percent of the biodegradable fraction of solid waste generated in the European Union (EU)[5]. A variety of technologies and systems types have proven to be viable for processing the organic fraction of MSW. There are both mesophilic (67 percent of projects) and thermophilic (33 percent of projects) systems. Most of these projects process exclusively MSW (89 percent), while others co-digest with other organic wastes (11 percent). There are both wet (38 percent) and dry (62 percent) systems, and systems that mechanically separate (45 percent) and source separate (55 percent) the organics from non-organic fractions of waste. In short, there are a variety of digester technologies commonly in use in Europe for processing the organic fraction of MSW and no clear technology winner.[6]

The EU is ahead of most other regions around the world when it comes to anaerobic digestion, particularly for processing the organic fraction of MSW. This success can be attributed to several factors. Countries like the Netherlands, Belgium, and Malta simply don't have enough space to keep using landfilling as a sustainable option for waste management. While AD can be more costly than other processing technologies (such as landfilling) it has many advantages such as the production of renewable energy, potential reduction of odor, and reduction of the need for permanent management of landfills. Some of the drivers in Europe include the Landfill Directive of 1999, which limits the amount of biodegradable municipal waste allowed in landfills, and feed-in tariffs, which offer a guaranteed above-market-price for electricity from renewable sources along with an increase in landfill taxes.[7]

There is much to learn from the EU's experience in operating AD systems with organic waste, and systems in the EU should be considered state-of-the-art in terms of technology and operations. The policy and regulatory environment, however, is very different in Europe. A successful project in the US will likely rely heavily on European

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[5] De Baere, Luc, and Bruno Mattheeuws. 2012. "Anaerobic Digestion of the Organic Fraction of Municipal Solid Waste in Europe – Status, Experience and Prospects." Essay. In *Waste Management: Recycling and Recovery*, 3:517–26. Neuruppin: TK Verlag Karl Thomé-Kozmiensky. http://www.ows.be/wp-content/uploads/2013/02/Anaerobic-digestion-of-the-organic-fraction-of-MSW-in-Europe.pdf.

[6] De Baere and Mattheeuws, "Anaerobic Digestion of the Organic Fraction of Municipal Solid Waste in Europe – Status, Experience and Prospects," 521-523.

[7] "Municipal Waste Management across European Countries." 2018. European Environment Agency. August 9, 2018. https://www.eea.europa.eu/themes/waste/municipal-waste/municipal-waste-management-across-european-countries.

experience with AD technology but will have to adapt its revenue model to the US policy and regulatory environment. Specifically, US projects will not be able to rely on the high electricity prices through feed-in tariffs that predominate in Europe.

STATUS IN NORTH AMERICA

AD is an established industry in the US, but there are relatively few stand-alone AD projects that focus on the organic fraction of municipal solid waste. Although data on the status of AD technology in Canada is not as readily available, we identified two notable projects processing the organic fraction of municipal solid waste that are relevant for this study.

The US Environmental Protection Agency (EPA) released a report in 2018 that summarized the extent of AD facilities processing food waste in the US. It identified 154 AD facilities that process food waste but only 61 stand-alone AD facilities that primarily process food waste. Only a subset of the 61 stand-alone facilities process the organic fraction of municipal solid waste, and the list includes potato processing plants, dairies, breweries, onion processing plants, beet processing plants, and other agricultural processing plants.

The 2018 EPA report did not identify which projects specifically focused on MSW, although a few are identified in the case studies section of this report. Of the 250 anaerobic digesters operating on farms, 43 accepted food waste as a supplemental source. Of the approximately 1,200 digestors at water resource recovery facilities (WRRFs), roughly 20 percent accepted outside materials for co-digestion, including food waste and other materials such as fats, oils, and greases, food processing industry waste, beverage processing industry waste, fruit and vegetable waste, and pre- and post-consumer food service waste. The survey found that the total processing capacity for food waste in AD systems in the US was 15,809,647 tons per year, and the total amount processed in 2015 in all digesters was 12,730,657 tons. In other words, these anaerobic digesters were processing 80 percent of their total capacity. Of that total, 77 percent was processed in stand-alone systems, 22 percent co-digested in WWRFs, and less than one percent in on-farm digesters. Many of the facilities were mesophilic and employed wet digestors with de-packaging and screening for debris commonly used as pre-processing strategies while 60 percent used gas clean-up technology. The report identified three stand-alone AD plants processing food waste in Minnesota: American Crystal Sugar in Moorhead, Hometown Bioenergy in Le Sueur, and American Crystal Sugar in East Grand Forks. [8]

[8] Pennington, Melissa. 2018. "Anaerobic Digestion Facilities Processing Food Waste in the United States in 2015." *Rep. Anaerobic Digestion Facilities Processing Food Waste in the United States in 2015.* Environmental Protection Agency. https://www.epa.gov/anaerobic-digestion/anaerobic-digestion-facilities-processing-food-waste-united-states-2015-survey.

Table 1: Uses of biogas produced at anaerobic digesters (2015)

	Stand-Alone Digesters		On-Farm Digesters		Co-Digestion Systems at WRRFs	
Biogas Use	*Number of Facilities Reporting Use*	*Percentage of Facilities using Biogas as Specified**	*Number of Facilities Reporting Use*	*Percentage of On-farm Digesters using Biogas as Specified†*	*Number of Facilities Reporting Use*	*Percentage of WRRFs using Biogas as Specified§*
Produce heat and electricity (CHP)	32	65%	13	87%	51	71%
Fuel boilers and furnaces to heat digesters	9	18%	2	13%	44	61%
Fuel boilers and furnaces to heat other spaces	16	33%	1	7%	23	32%
Produce electricity (sold to grid)	20	41%	10	67%	9	13%
Produce electricity used behind the meter (including net metering)	14	29%	8	53%	16	22%
Produce mechanical power	2	4%	2	13%	4	6%
Compressed to vehicle fuels: used for company fleet/personal vehicles	4	8%	0	--	0	--
Compressed to vehicle fuels: sold to customers	3	6%	0	--	1	1%
Renewable natural gas (processed in order to inject to pipeline)	2	4%	0	--	2	3%
*: Percentage out of the 49 facilities providing data on biogas uses.						
†: Percentage out of the 15 farms providing survey responses.						
§: Percentage out of the 72 WRRFs providing survey responses.						

Source: Table reproduced from Pennington, "Anaerobic Digestion Facilities Processing Food Waste in the United States in 2015."

Nearly all facilities surveyed were generating combined heat and power, or one or the other (heat or power). Of the facilities surveyed, 65 percent produced heat and electricity, 18 percent fueled boilers and furnaces to heat other spaces, 41 percent produce electricity to sell to the grid, 29 percent produce electricity for use behind the meter. Only seven facilities reported compressing biogas for use in vehicles, and only two reported producing renewable natural gas that was processed to inject into the pipeline.

The American Biogas Council maintains data on agricultural, landfill, and wastewater AD systems but does not currently track food waste AD systems. Data collected includes basic information about each project (location, digestion type, the volume of waste, type of energy production if any, etc.).

We could not identify high-level data on existing AD projects in Canada, but we were able to identify two notable projects that are processing the organic fraction of municipal solid waste. These projects are included among the case studies described below.

CASE STUDIES

Hometown Bioenergy

Location: Le Sueur, Minnesota

Description: The Hometown Bioenergy facility started operating in 2014. It uses anaerobic digestion to turn agricultural and food processing wastes into biogas. It then burns the biogas in reciprocating engines to produce electricity. The process also produces digestate, which is a fertilizer rich in nutrients that is separated into solid and liquid and later sold to local farmers. What makes this facility unique is their significant electricity storage of 950,000 standard cubic feet (SCF), which allows it to generate electricity during peak hours when electricity generating is more valuable. It is also connected to the City of Le Sueur's electric grid, which saves transmission costs and reduces line losses.[9] The project used technology from Xergi A/S, a Danish biogas technology provider.

Feedstock: Agricultural and food processing waste. The plant manages a mixture of wet and dry feedstocks.

Technology: The plant's flexible design allows for a wet or dry continuous treatment of feedstocks. Designed by Xergi A/S (Danish).

Products: The plant produces 8 MW of electricity annually along with solid and liquid byproduct that is later sold as fertilizer.

Challenges: Several challenges have been reported. The facility was fined by the Minnesota Pollution Control Agency for air violations. Early in the project's life, there were reports of odor complaints in the community. Finally, the variability of the feedstock received has impacted plant operations, causing reductions in yield and plant shut-downs.[10]

Relevance: Storing gas to benefit from higher-peak electricity costs is an innovative feature that could be explored. Operational challenges including lower than expected yields, inconsistent operations, and odor problems should be studied and avoided.

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[9] "Hometown BioEnergy." n.d. Minnesota Municipal Power Agency. Accessed August 20, 2018. https://www.mmpa.org/power-supply/hometown-bioenergy/.

[10] Shaffer, David. 2015. "Slow, Stinky Start to Le Sueur, Minn., Green-Energy Project." Star Tribune. Star Tribune. October 17, 2015. http://www.startribune.com/slow-stinky-start-to-le-sueur-minn-green-energy-project/333334521/.

CR&R Digester

Location: Perris, California.

Description: This large-scale facility was fully operational in April of 2017. The facility features four parallel, primary digesters that are automatically fed through conveyors and dosing bins. CR&R is one of two projects with a renewable natural gas (RNG) interconnect in California which, in partnership with the Southern California Gas Company, allows them to distribute their Renewable Natural Gas anywhere in the state.[11] The overall project cost is over $100 million.[12]

Feedstock: 335,000 tons a year of source-separated organics.

Technology: Continuous, high-solids, multi-stage. Eisenmann AD technology (German). Greenlane Biogas technology for gas clean-up and compression.

Products: 4 million gallons of RNG annually, and 250,000 tons of soil products.

Challenges: None documented.

Relevance: The project is relevant in that it uses MSW as a feedstock and was deployed to help meet state recycling and landfill diversion goals. It is a model for a potential project in the Twin Cities that might produce RNG and effectively market soil products. It operates near residential areas, and there are likely lessons to be learned about odor control. The project is being built in multiple stages, with each unit handling 83,600 tons per year. A staged approach could be considered for future projects.

Incline Clean Energy

Location: Sacramento, California.

Description: This system, formerly known as the Sacramento BioDigester, was formerly operated by CleanWorld. It is now operated by Incline Energy. It uses an anaerobic phased solids system developed and patented by a professor at the University of California-Davis. The facility is designed to handle 100 tons per day and has equipment for gas clean-up and compression to provide compressed natural gas for vehicles. The project received a $6 million grant from the California Energy Commission and $2 million in loans from CalRecycle's Recycling Market Development Zone program. The total project cost was around $12 million. The project has had trouble and is not currently operating according to news reports.

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[11] "The Largest Anaerobic Digester in the United States Sets the Green Pace in Perris, California." n.d. Case Studies: RNG Project Profiles. Energy Vision. Accessed August 8, 2018. https://energy-vision.org/pdf/CR&R_Project_Profile.pdf.

[12] Miller-Coleman, Nicole. 2017. "Perris Facility to Meet State's Environmental Goals." Sandiegouniontribune.com. August 9, 2017. http://www.sandiegouniontribune.com/news/sd-tm-0729-digester-20170719-story.html.

Feedstock: 100 tons a day of solid organic waste.

Technology: Continuous, high-solids, thermophilic, multi-stage.

Products: 3.17 million kilowatt hours of electricity annually, CNG for vehicles.

Challenges: This facility faced some challenges since its opening date of 2014. The plant faced three main challenges including odor, identifying the best feedstocks, and identifying the best processing technology approaches. It tried to reduce odor emissions by accepting liquid waste only. It stopped accepting solid food waste in 2017 but challenges persisted, forcing it to stop accepting liquid waste as well by early 2018.[13]

Relevance: It manages similar materials (e.g., MSW) and pursues similar strategies for revenue (e.g., CNG, electricity sales) to what a new project might consider.

San Luis Obispo Facility

Location: Central Coast, California

Description: This facility utilizes mechanical pre-treatment that processes feedstock through a shredder, which is followed by a two-inch star screen that removes contaminants such as plastic, paper, ferromagnetic particles, and other non-organic items. Additionally, the handling of organic materials takes place in closed and ventilated rooms, minimizing odor emissions.[14] Calrecycle will pay for $4 million of the project cost.

Feedstock: 100 tons per day of source separated organics.

Technology: Continuous, high-solids, multi-stage. Designed, financed, built and operated by Hitachi Zosen Inova AG (HZI), Zurich, Switzerland. Kampogas technology. Thermophilic dry digestion.

Products: The biogas produced is burned to generate electricity. The electricity produced is expected to power around 700 homes.

Challenges: The project is under construction and it is unclear what challenges they will confront.

Relevance: This will be a closed system with biofiltration to avoid odor and emissions. Project developers rely on proven European technology to avoid operational challenges. The facility produces electricity rather than CNG due to lack of sufficient demand for CNG onsite.

[13] Karidis, Arlene. 2018. “Sacramento, Calif., Anaerobic Digester Goes Back to the Drawing Board.” Waste360. April 16, 2018. https://www.waste360.com/anaerobic-digestion/sacramento-calif-anaerobic-digester-goes-back-drawing-board.

[14] McMahon, Jim. 2018. “Anaerobic Digestion Facility Nears Completion in California.” Waste Today. February 2, 2018. http://www.wastetodaymagazine.com/article/anaerobic-digestion-san-luis-county.

UW Oshkosh Urban Dry Digester

Location: Oshkosh, Wisconsin, US

Description: Owned by University of Wisconsin Oshkosh Foundation and developed by BioFerm Energy Systems, this system utilizes dry fermentation to process food waste, yard waste, and farm residuals. The project produces electricity and compost. The facility cost $4.7 million and was financed in part with grants from the Wisconsin State Energy Office and US Treasury 1603 program.

Feedstock: Food waste, yard waste, and farm residuals. Capacity to handle 8,000 tons per year.

Technology: Dry digestion technology from BioFerm.

Products: Produces 2,320 mWh of electricity per year, sufficient to provide about 15 percent of the power needs of the UW Oshkosh campus.

Challenges: No significant challenges reported.

Relevance: Dry digestion could be relevant, depending on the feedstock selected for digestion. This is an example of a food waste digester operating outside of Europe and California, which have unique policy environments.

Biocel Leach-Bed Batch

Location: Lelystad, Netherlands.

Description: This facility can digest a variety of feedstocks by using a simple dry system and avoiding the complications that come with a more sophisticated design. It also features a depackaging line that removes packaging from expired products and breaks down the remaining waste for AD. Additionally, the building and the facilities are kept under negative pressure and all the air is thoroughly cleaned before it is emitted into the surrounding area, which guarantees virtually no odors. [15]

Feedstock: 50,000 tons per year of source-separated organic fraction of MSW.

Technology: High solids, a combination of mesophilic and thermophilic management. The facility uses Biocel digestion technology from Orgaworld.

Products: The biogas produced is used to generate four million kWh of electricity per year which is converted into energy and heat. The plant also puts out 10.000 tons of compost per year.

Challenges: We are unaware of any major challenges with this facility.

[15] "Lelystad: Biocel Anaerobic Digestion and Composting Plant." n.d. Orgaworld. Accessed August 6, 2018. https://www.orgaworld.com/more-about-our-business/our-locations/lelystad-biocel.

Relevance: Relevance of dry digestion depends on the feedstock that needs to be processed. Dryer materials include leaf and yard waste. The project claims reliable operation for 20 years and effective odor control. The facility also claims to have an effective depackaging strategy. The technology is designed to pair with composting to manage the digestate.

Disco Road Organics Processing Facility

Location: Toronto, Ontario

Description: The facility is owned by the City of Toronto and operated by private operators AECOM, Veolia North America, and CCI BioEnergy, Inc. This project is part of Toronto's plan for reaching a 70 percent waste diversion rate.[16]

Feedstock: 83,000 tons per year of source separated organics. As of 2016, the facility was planning an upgrade to process 143,000 tons per year.

Technology: Wet single-stage mesophilic. The plant uses a BTA process licensed from CCI BioEnergy.

Products: Digestate for composting and fertilizer and biogas for electricity generation and heat recovery.

Challenges: We are unaware of major challenges with this facility.

Relevance: This facility processes municipal organics and is located near a residential area. It may offer lessons on odor control for public acceptance of a project. The project operates with more limited revenue streams from electricity and heat, whereas our analysis suggests that higher revenue potential exists from renewable fuel policy credits.

Surrey Biofuel Facility

Location: Surrey, British Columbia

Description: Costing $68 million to build,[17] the facility began operating in the summer of 2018 and is designed to help the City of Surrey and Metro Vancouver area achieve its regional 80 percent diversion target.[18]

Feedstock: 115,000 tons of source-separated organics per year.

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[16] Gorrie, Peter. 2015. "Toronto Expands Anaerobic Digestion of Source Separated Organics." BioCycle. February 13, 2015. https://www.biocycle.net/2015/02/13/toronto-expands-anaerobic-digestion-of-source-separated-organics.

[17] Allan, Lesley. 2018. "BC City Using Biofuel to Power Waste Management System." Canadian Biomass. Canadian Biomass. May 28, 2018. https://www.canadianbiomassmagazine.ca/biofuel/fuelling-waste-collection-6842.

[18] Messenger, Ben. 2018. "Renewi's Anaerobic Digestion & Compost Plant Reach 'Full Service' in Surrey, BC." Waste Management World. Waste Management World. June 18, 2018. https://waste-management-world.com/a/renewis-anaerobic-digestion-compost-plant-reach-full-service-in-surrey-bc.

Technology: Both wet and dry digestion technologies working together.

Products: It’s estimated to produce 120,000 gigajoules of renewable natural gas to power the city’s waste collection trucks and feed the city’s district energy system and produce 45,000 tons of compost per year.

Challenges: We are unaware of major challenges with this facility.

Relevance: This project is highly relevant in its scale, business model (revenues from LCFS and transportation fuels), and intent, which is to meet higher waste diversion targets.

Policy and Regulatory Considerations

ENVIRONMENTAL PERMITTING

As with any industrial project, an anaerobic digestion (AD) project would need to complete a comprehensive review of environmental impacts to determine the full suite of federal, state, and local regulatory requirements necessary to build and operate the facility.

In Minnesota, the first step in that process would include completing an Environmental Assessment Worksheet (EAW). The EAW not only determines certain regulatory requirements, but it is also a useful first step in stakeholder engagement. The EAW informs the public about the project while also identifies strategies to minimize environmental impacts. A similar environmental review based on the National Environmental Policy Act may be required depending on what role, if any, the federal government has in the project.

Final permitting requirements will be established after completing the EAW and complementary analyses of the site and operational requirements. Based on advice and analysis from a local engineering firm with expertise in industrial permitting requirements, it is expected that permitting activities related to the following would need to be completed:

- Air permitting to include emissions and odor countermeasures
- Solid waste
- Construction Stormwater Pollution Prevention Plan
- Hazardous Waste License
- Industrial Stormwater Pollution Prevention Plan
- Process and Sanitary Water Permit
- Wastewater Discharge Permit
- Tankage Requirements and Permitting
- Spill Prevention, Control and Counter Measure Plan
- Environmental Risk Mitigation and Employee Safety Plan
- National Environmental Policy Act Review (as necessary)

Early engagement with both regulators and project stakeholders will be critical for an efficient permitting and construction process followed by a successful operations phase. The Great Plains Institute recommends collaboration between the counties to engage policy makers, technology providers, and citizens with the support of this study to educate key decision makers and other key stakeholders to help a project move forward. Doing so will enhance the likelihood that the economic, environmental, and social benefits that may be possible from an anaerobic digestion project in the Twin Cities metro area will be realized and contribute to meeting the ambitious recycling goals established by the State of Minnesota.

Additional permitting requirements exist for an AD project that intends to deliver biogas to a pipeline network capable of delivering it to the California market to capture valuable carbon credits from the state's Low Carbon Fuel Standard. There are two relevant state regulatory authorities for pipelines in Minnesota. The Office of Pipeline Safety sets and enforces safety standards through policies related to maintenance requirements, accident notification, and other standards. The Minnesota Public Utilities Commission has routing and permitting authority. The commission's authority includes granting certificates of need and site or route permits. The certificate of need process includes determinations related to basic type and size of the facility consistent with state policies related to environmental preservation and the efficient use of resources. The Department of Commerce, Energy Environmental Review and Analysis staff conducts an environmental review, provides technical expertise and submits recommendations to the commission for routing applications. This process can take 12 months. Owners and operators of interstate natural gas pipelines are regulated pursuant to the federal Natural Gas Act and rules administered by the Federal Energy Regulatory Commission. Given the complexities of pipeline issues, it is recommended that the early stakeholder engagement process include outreach to pipeline operators and regulatory authorities.

Summary of Environmental Initiatives, Mandates, and Goals Established or Discussed by County Decision Makers.

The primary goals established by county decision makers are the County Solid Waste Management Master Plans and the state recycling goal of 75 percent.

Siting Considerations

An efficient site selection process is more a site "elimination" process. Location screening and scoring criteria, beginning with high-level, large geographic considerations and then evolving into site-specific considerations, will guide project managers through a progressively shorter list of potential locations suitable for an anaerobic digestion project in the Twin Cities metro area.

Prior to beginning the site selection process, it is critical to first define the project scope and its corresponding operational requirements to evaluate location opportunities and the permitting profile. The following considerations would need to be scrutinized based on the scale of the project to guide the site selection process:

- **Inbound shipments of feedstock and other materials for operation**: sources, volumes, frequency, and modes of transportation.
- **Outbound shipments of digestate and other outputs:** sources, volumes, frequency, and modes of transportation.
- **Labor requirements:** Number and type of jobs, shifts, and labor/management dynamics.
- **Site requirements:** Size, configuration, and onsite storage requirements.
- **Electric power:** Demand and consumption by month, line size, and redundancies.
- **Natural gas:** Consumption by month, line size, and redundancies.

- ❑ **Water:** Usage (volumes by day, month, peak), line size, redundancies, and mitigation.
- ❑ **Wastewater:** Discharge volumes and effluent characteristics.
- ❑ **Air emissions:** Description and estimated volumes and dispersion modeling as needed.
- ❑ **Community preferences:** Community characteristics/culture, highway proximity and available infrastructure, and sustainability considerations.
- ❑ **Project investment:** Estimated value of land and building, equipment purchases and installation, and start-up costs.
- ❑ **Incentives:** Availability of incentive programs including tax credits, loans, grants, and other financing assistance.
- ❑ **Project timeline:** Target real estate acquisition date, construction schedule and utility engagement, equipment commissioning, staffing, and production startup.

Once operational requirements for the project are defined, the next step is to begin using the criteria to narrow the search, beginning with those that can be measured at a high level, allowing for the quickest possible elimination of non-qualifying sites. Accordingly, transportation and logistics, especially in the context of feedstock delivery, will be a primary consideration for the project as will the availability of cost-efficient utility connections. Real estate considerations such as costs and availability of existing suitable buildings would also be considered at this stage, as would tax liabilities and the general regulatory environment for sites under consideration.

Step three in the process would be to further scrutinize site and community-level analyses further narrowing the list of suitable site options. Once focused in on a small list of potential areas in the metro that meet the minimum search criteria, the next step is to conduct a detailed evaluation of specific properties and communities to select the optimal location for operational requirements for the project. Those factors may fall into three categories of property issues, community issues, and state and local incentives. Property issues primarily relate to physical characteristics, transportation infrastructure, utility requirements and availability, zoning, and environmental conditions. Labor force, water and wastewater infrastructure, community development trends, local economic profile, regulations, sustainability, and community support are among the community issues that should be considered. Early engagement with key decision makers and economic development authorities to highlight the benefits of the project is key to maximizing benefits from the available state, local, and utility service incentives.

Once finalist locations are selected, it is prudent to conduct detailed property due diligence to obtain commitments on utility services and other needs, as well as to ensure there are no surprises once the first shovel goes into the ground for development. At this phase, it may be appropriate to engage an engineering firm to assist with the technical review of the site attributes.

If considering a site that has not been previously developed, you may need to conduct several site studies (e.g., phase 1 environmental study, geotechnical analysis, hydrologic analysis, site survey, archaeological study, endangered species analysis) and other technical site reviews pertaining to the development of the site. Detailed lists of comprehensive due diligence activities related to real estate acquisitions and site conditions should be considered with real estate and engineering experts. During the due diligence, formal incentives negotiations for a final site should be initiated. For maximum leverage, it is recommended to have at least two finalist locations in different economic zones. Expedited permitting and reduced operating costs in the form of tax credits and utility riders are examples of incentives that may be explored. As finalist locations, both should be able to meet operational needs; so, at this step, a detailed financial analysis for each finalist site should be developed to determine which incentive package provides the most in terms of upfront and/or cost savings and risk management.

The final step of the site selection process is property acquisition and to begin detailed engineering of the facility and implementation of the project timeline that includes all necessary environmental permitting activities.

Stakeholder Identification and Engagement

Stakeholders should be engaged early in the process to ensure success moving forward. Categories of stakeholders include the feedstock supply chain, county leaders, and state policy leaders, investors and technology providers, county residents, the environmental NGO community, and natural gas and electric utilities. Other stakeholders may include operators of large fleets of vehicles that could utilize natural gas as a transportation fuel and compost sites that can utilize the digestate. Many of these groups participated in the Anaerobic Digestion Task Force which met two times as part of the research process leading up to this report. Additional stakeholders will be engaged following the finalization of this report.

Incentives Through Policy and Voluntary Environmental Programs

RENEWABLE FUEL STANDARD

According to the EPA's website, the Renewable Fuel Standard (RFS) program was created under the Energy Policy Act of 2005 and amended by the Energy Independence and Security Act of 2007 (EISA). The 2007 enactment of EISA significantly increased the size of the program and included key changes, such as boosting the long-term annual goal to 36 billion gallons of renewable fuel. EPA implements the program in consultation with the US Department of Agriculture and Department of Energy. The RFS program is a national policy that requires a certain volume of renewable fuel to replace or reduce the quantity of petroleum-based transportation fuel, heating oil, or jet fuel. The four renewable fuel categories under the RFS are:

- Biomass-based diesel must meet a 50 percent lifecycle greenhouse gas (GHG) reduction (D4 RIN)
- Cellulosic biofuel must be produced from cellulose, hemicellulose, or lignin and must meet a 60 percent lifecycle GHG reduction (D3 RIN)
- Advanced biofuel can be produced from qualifying renewable biomass (except cornstarch) and must meet a 50 percent GHG reduction (D5 RIN)
- Renewable (or conventional) fuel typically refers to ethanol derived from corn starch and must meet a 20 percent lifecycle GHG reduction threshold (D6 RIN)

Obligated parties under the RFS program are refiners or importers of gasoline or diesel fuel. Compliance is achieved by blending renewable fuels into transportation fuel, or by obtaining credits (called "Renewable Identification Numbers" or RINs) to meet an EPA-specified Renewable Volume Obligation (RVO). To generate a RIN, fuel producers must demonstrate GHG emissions reduction compared with baseline levels for traditional fuels by establishing a new pathway or complying with an existing pathway. As of today, two pathways, Q and T, have been established that cover biogas produced by waste digesters. Municipal solid waste (MSW) digesters have qualified for D5 RINs based on life-cycle assessments but enhancements to digester technology may yield processes that qualify for the more valuable D3 RINs in the future.

LOW CARBON FUEL STANDARD

The Low Carbon Fuel Standard (LCFS) is designed to encourage the use of cleaner low-carbon fuels in California and encourage the production of those fuels, thereby reducing GHG emissions. The LCFS standards are expressed in terms of the "carbon intensity" (CI) of gasoline and diesel fuel and their respective substitutes. The LCFS is performance-based and fuel-neutral, allowing the market to determine how the carbon intensity of California's transportation fuels will be reduced. This program is based on the principle that each fuel has "lifecycle" GHG emissions that includes GHG contributors.

The lifecycle assessment examines the GHG emissions associated with the production, transportation, and use of a given fuel. The lifecycle assessment includes direct emissions associated with producing, transporting, and using the fuels, as well as significant indirect effects on GHG emissions, such as changes in land use for some biofuels. Subjecting this lifecycle GHG rating to a declining standard for the transportation fuel pool in California would result in a decrease in the total lifecycle GHG emissions from fuels used in California. Like the RFS program, fuel producers must demonstrate compliance with pathways to produce qualifying fuels that are delivered to California. The program has approved a variety of pathways for liquefied and compressed natural gas produced inclusive of MSW-based anaerobic digestion (AD) projects.

MINNESOTA'S AGRI BIOINCENTIVE PROGRAM

The AGRI Bioincentive Program, administered by the Minnesota Department of Agriculture, was established by the Minnesota Legislature during the 2015 session to encourage commercial-scale production of advanced biofuels, renewable chemicals, and biomass thermal energy through production incentive payments.[19]

Incentive payments are available for three types of production: advanced biofuels, renewable chemicals, and biomass thermal energy. Payment rates are established in statute. Also established in statute are criteria for minimum production levels and standards for the sourcing of biomass feedstock. A minimum of 80 percent of the biomass must be obtained ("sourced") from Minnesota. The program receives funding from the Agricultural Growth, Research, and Innovation (AGRI) program appropriation. Current funding is $1.5 million for each year of the biennium.

An AD project could be eligible for both the advanced biofuel incentive and the biomass thermal incentive. GPI did not model scenarios for revenue from thermal energy and thus only incorporated the advanced biofuel incentive into the model. To qualify, a facility must demonstrate that they have an advanced biofuel pathway approved by the US EPA under the RFS and they must document production on a quarterly basis. The project would be eligible for this incentive for a 10-year period.

RENEWABLE PORTFOLIO STANDARD

Minnesota electric utilities have a statutory requirement to generate a percentage of their electricity from renewable sources. Electricity from biogas is an eligible source. This policy and policies in other states create a premium for generation of renewable electricity. In practice, however, the low cost of wind results in a minimal price premium and low values for tradeable renewable electricity credits. GPI did not assume a price premium for electricity from biogas as a result.

[19] Revisor of Statutes, State of Minnesota, 41A.15-41A.19. 2017.

VOLUNTARY PROGRAMS

CenterPoint Energy filed a proposal with the Minnesota Public Utilities Commission seeking to establish a voluntary renewable natural gas green tariff program. This program, if approved, would allow natural gas customers to opt-in and purchase renewable natural gas at a premium price. Programs like this could create another revenue opportunity for AD projects if they take hold and achieve sufficient scale of adoption. Due to the uncertainty around the timing, scale, and price impacts of this program, GPI did not model it as a source of revenue for a project.

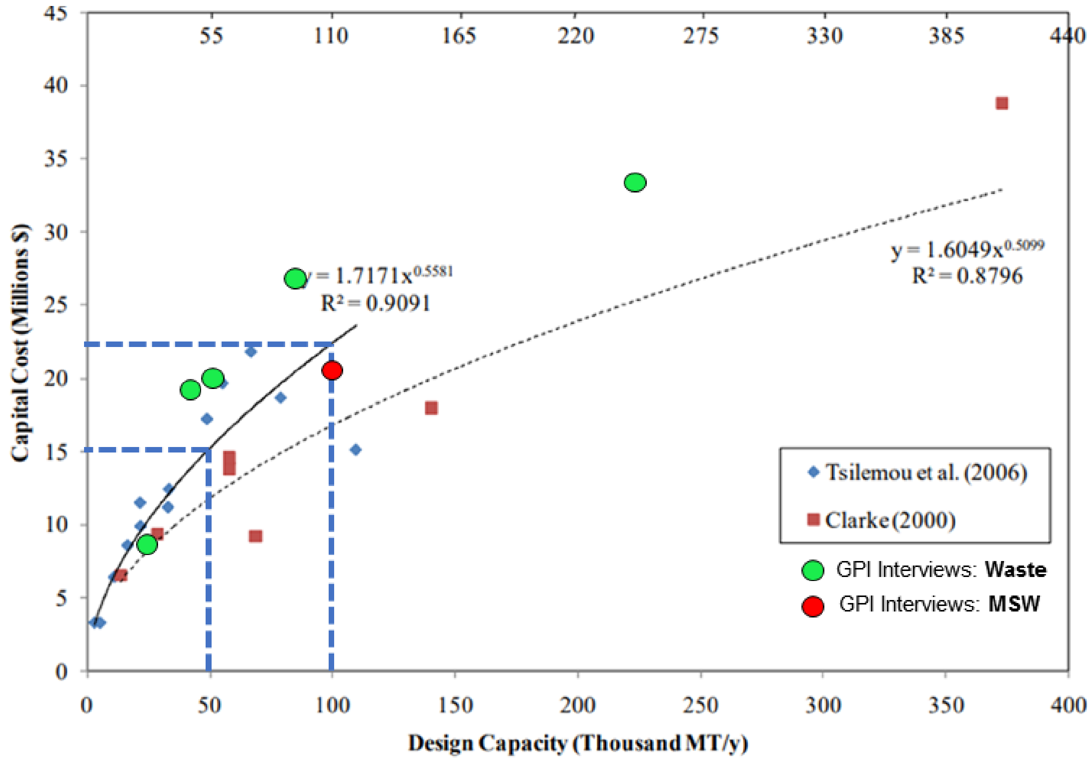
Economic and Environmental Factors

CAPITAL AND OPERATING COSTS

A literature review for assessing the capital and operating costs of anaerobic digestion (AD) facilities found very little public information regarding MSW digesters in North America. A study conducted for the California Integrated Waste Management Board (which, since this study, became a part of CalRecycle and no longer exists) by the University of California Davis Department of Biological and Agricultural Engineering published cost curves based on European municipal solid waste (MSW) anaerobic digesters.[20] Interviews conducted by GPI for this study revealed that capital costs of Minnesota-based digesters were generally in line with these results (see figure 1). According to the UC Davis report, expected total capital costs for 50,000 to 100,000 tons per year (TPY) facility would be approximately $15 million to $23 million (2007 US dollars), including all pre-development and construction costs.

[20] Rapport et al., 2008, 60.

Figure 1. Capital costs of anaerobic digesters from a UC Davis study

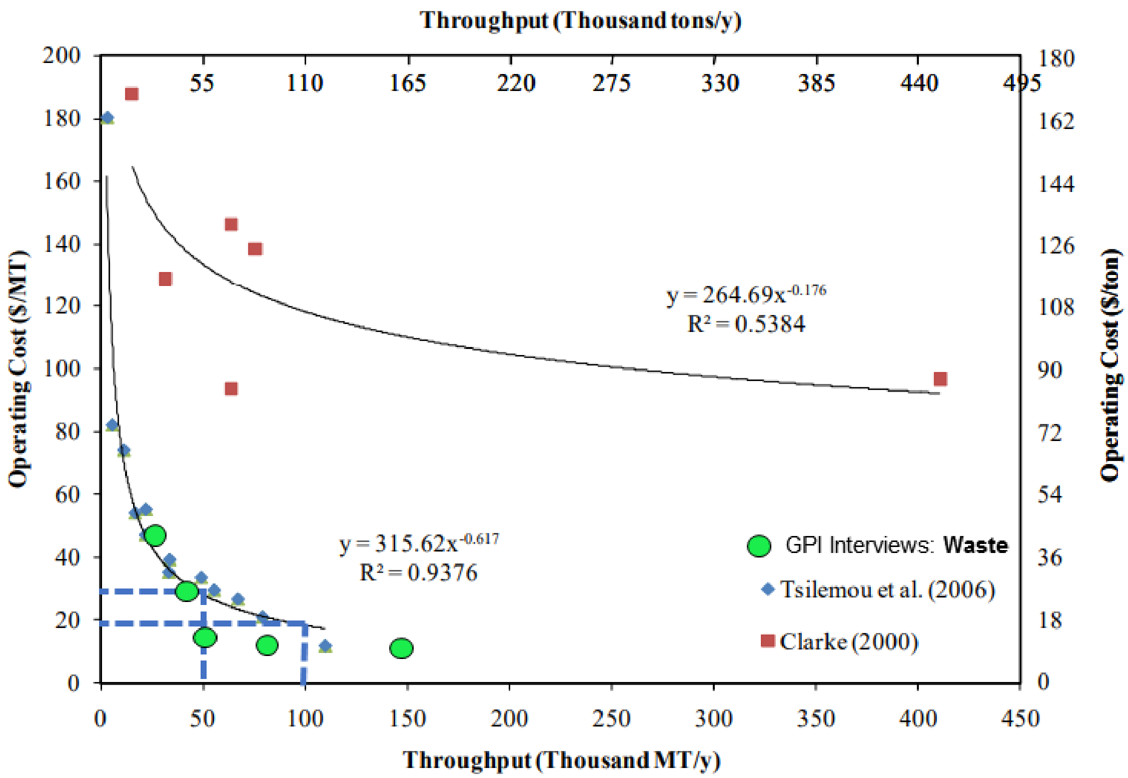


Note: Findings from GPI interviews of Minnesota waste digesters are superimposed on the original figure as red and green circles (see key). Waste includes all types of waste whereas MSW is limited to that generated by municipalities.

Source: Rapport, et al., 2008.

The UC Davis study also provided operating cost curves based on European MSW digesters (see figure 2). While fewer Minnesota operators were able to provide annual operating costs during GPI interviews, these were found to be generally in line with the published data as well. Therefore, operating costs may be expected to be around $30 per ton for a 50,000 TPY facility and around $20 per ton for a 100,000 TPY facility. Operating costs published by UC Davis include labor, maintenance, materials, testing, insurance, overheads, and training costs (but not waste transportation).

Figure 2. Operating costs of anaerobic digesters from a UC Davis study



Note: Findings from GPI interviews of Minnesota waste digesters are superimposed as red and green circles (see key).

Source: Rapport, et al., 2008.

While comparing potential costs and revenues under multiple scenarios, it is important to be able to assess prices on an equivalent basis. The primary energy produced by biogas can be expressed in the standard unit of measurement: million British thermal units, or MMBtu. Therefore, costs and revenues are converted to a per MMBtu basis for this study.

A more recent study published by UC Davis in 2016 consolidated the capital and operating cost curves into a single non-feedstock production cost curve.[21] According to this curve, a 50,000 TPY MSW digester would cost approximately $35 per MMBtu to construct and operate, while a 100,000 TPY facility would cost approximately $27 per MMBtu. The costs of this more recent study are used in this analysis to assess the financial performance of each scenario.

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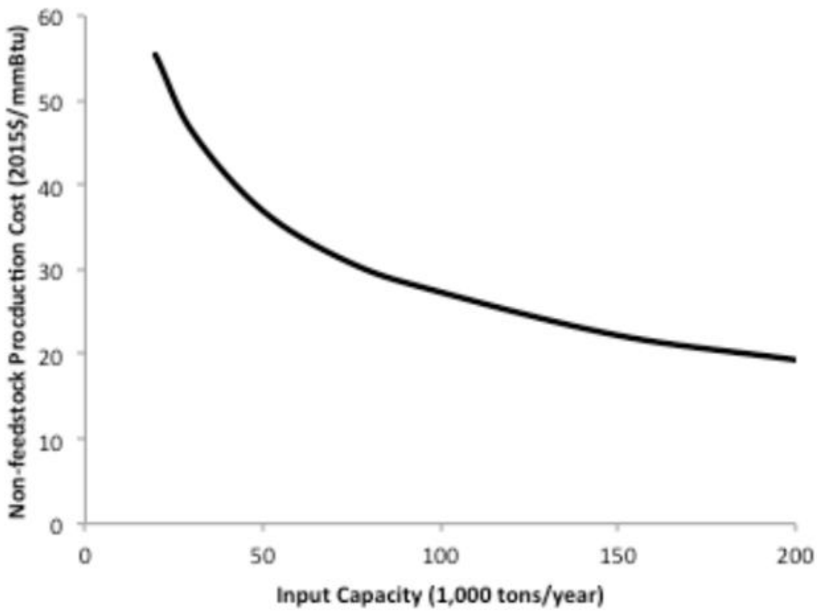
[21] Jaffe et al., 2016, "Final Draft Report on The Feasibility of Renewable Natural Gas as a Large-Scale, Low Carbon Substitute."

Figure 3: Amortized production cost curve per energy produced for MSW anaerobic digesters from a UC Davis study



Source: Jaffe et al., 2016, "Final Draft Report on The Feasibility of Renewable Natural Gas as a Large-Scale, Low Carbon Substitute."

PROCESSING VOLUME SCENARIOS

Based on research and industry interviews conducted by GPI, a range of feedstock processing volume scenarios was modeled to assess economic performance at varying levels of waste volume and bioenergy product program participation or credit qualification (e.g., EPA's Renewable Fuel Standard program). Previous studies for Ramsey and Washington counties projected sufficient levels of the organic waste collection to support the processing of at least 100,000 TPY.[22] This report also considers waste collection for Hennepin County as well, so the analysis presented here is not meant to preclude facilities that could process even greater volumes. Generally, facilities discussed during GPI's industry interviews were in the range of 25,000 to 100,000 TPY, with two outliers at 150,000 (ag waste) and 219,000 (beet tailings) TPY.

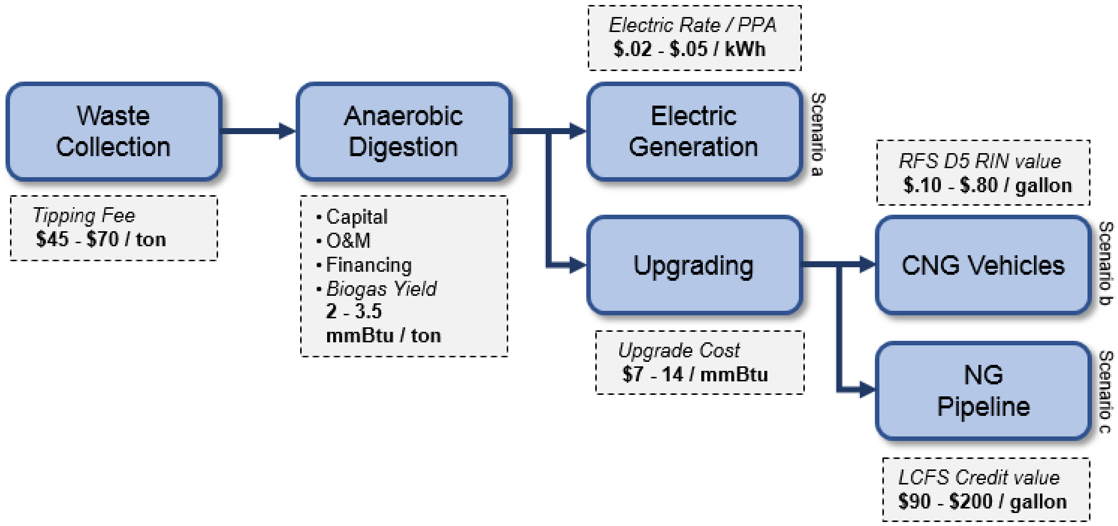
Three primary uses for biogas were considered: onsite electric generation, partial upgrading and compression to compressed natural gas (CNG) for transportation vehicles, and pipeline-quality upgrading for sale to the California Low Carbon Fuel Standard (LCFS) market. Additionally, these bioenergy products would qualify for Minnesota's AGRI Bioincentive Program as an advanced biofuel.[23] The simplest process is to burn biogas in a combustion engine or generation turbine to produce onsite electricity. This electricity can be sold to an electric utility at rates determined by a power purchase agreement or used onsite and considered as a credit for cost avoided.

Upgrading the biogas product and compressing for use as bio-CNG for transportation vehicles creates the potential for receiving renewable identification numbers (RINs) for biofuel production under the US EPA's Renewable Fuel Standard (RFS).[24] EPA's track record has been to approve D5 RINs for MSW AD projects; however, it is possible that such projects could qualify for more valuable D3 RINs. More extensive upgrading to pipeline quality and interconnection to natural gas transportation pipelines could open access to California LCFS credits, which this study found to be the most valuable credit available for bioenergy products.

Figure 4 presents a flowchart of these possible processing scenarios and the primary cost or revenue drivers at each stage.

[22] Foth, "Alternative Technologies."
[23] "AGRI Bioincentive Program." n.d. Minnesota Department of Agriculture. Accessed September 8, 2018. http://www.mda.state.mn.us/environment-sustainability/agri-bioincentive-program.
[24] EPA, "Renewable Identification Numbers (RINs)."

Figure 4. Production scenario flow chart with significant costs and revenue sources at each stage



Source: Great Plains Institute, 2018.

It is expected that this facility would collect tipping fees for accepting and handling waste. A previous study identified a potential range for tipping fees at $50 – 60 per ton for a small AD facility. However, the same study also found tipping fees to be as low as $35 per ton for separated organic waste in general in the Twin Cities metro area.[25] Based on contracted organics processing fees currently paid by Hennepin, Ramsey, and Washington counties, it seems plausible in the future that a local AD facility could charge a tipping fee as high as $70 per ton. For this study, three yield/revenue scenarios were considered with tipping fees of $45, $58, and $70 per ton.

One of the most significant factors in the operation of an AD facility is the biogas yield. Literature suggests that an average yield for full-scale MSW digesters is around 1.8 standard cubic feet of biogas per pound.[26] Equally important to the yield is the methane or energy content, which can range from 40 to 70 percent methane by volume.[27] Studies conducted by the UC Davis Institute of Transportation Studies calculated an energy yield

[25] Foth, "Alternative Technologies."
[26] Rapport, Joshua, Ruihong Zhang, Bryan M Jenkins, and Robert B Williams. 2008. "Current Anaerobic Digestion Technologies Used for Treatment of Municipal Organic Solid Waste." Rep. *Current Anaerobic Digestion Technologies Used for Treatment of Municipal Organic Solid Waste*. Sacramento, CA: Integrated Waste Management Board.
[27] Rapport et al., 2008, 60-61.

of 2.16 MMBtu per ton of waste based on expected composition in California.[28] Findings by Foth, 2013 for Ramsey County/Washington County assumed energy production of 350,000 MMBtu per year for a 100,000 ton per year facility, resulting in an energy yield of 3.5 MMBtu per ton. Actual yields for the digestion of waste from Hennepin, Ramsey, and Washington counties will depend on the actual composition of organic waste, specific configuration, and design of the digestion facility, among other factors. This study uses the yield estimates produced locally by Foth for its *expected* yield scenarios, rather than relying on yield estimates from California or European studies. The lower yield (2.16 MMBtu per ton) is considered in the *low-yield* scenarios, as is explained in detail later in this section.

Table 2. Processing volume scenarios considered by this study

Waste Volume	Scenario	Bioenergy Product
1. 50,000 tons	1a	Electricity
	1b	CNG
	1c	Pipeline Gas
2. 100,000 tons	2a	Electricity
	2b	CNG
	2c	Pipeline Gas

In scenarios 1a and 2a, biogas is burned in a combustion engine or generation turbine to produce electricity. According to the US Department of Energy's Energy Information Administration (EIA), burning gas for electricity can produce approximately 127 kWh per MMBtu, though this depends on the quality and energy content of the gas, as well as on the type of engine or generator being used.[29] Electricity may be used onsite or may be sold back to the electric utility. According to the Xcel Energy (Xcel) / Northern States Power Company (NSP) Minnesota Electric Rate Book, payments to the generator from the utility may range from approximately $0.02 to $0.03 per kWh.[30] Discussions with the Anaerobic Digestion Task Force on August 29, 2018, pointed out that the facility operator may negotiate a power purchase agreement with the utility for slightly higher rates. Additionally, in the case of onsite electricity use this potential revenue could alternatively be considered a cost-avoidance at a much higher rate. At the time of this

[28] Jaffe, Amy Myers, Rosa Dominguez-Faus, Nathan Parker, Daniel Scheitrum, Justin Wilcock, and Marshall Miller. 2016. "Final Draft Report on The Feasibility of Renewable Natural Gas as a Large-Scale, Low Carbon Substitute." Rep. *Final Draft Report on The Feasibility of Renewable Natural Gas as a Large-Scale, Low Carbon Substitute*. UC Davis. https://steps.ucdavis.edu/the-feasibility-of-renewable-natural-gas-as-a-large-scale-low-carbon-substitute.

[29] "Monthly Energy Review." 2018. U.S. Energy Information Administration Independent Statistics and Analysis. August 28, 2018. https://www.eia.gov/totalenergy/data/monthly/. Accessed September 14, 2018

[30] "Minnesota Electric Rate Book-MPUC No. 2, Section 9-3." 2018. Xcel Energy. Northern States Power Company. April 1, 2018. https://www.xcelenergy.com/staticfiles/xe/PDF/Regulatory/Me_Section_9.pdf.

writing, Xcel commercial and industrial rates were $0.04260 per kWh for off-peak usage and an average of $0.13148 per kWh for on-peak usage.[31] For this study, three yield/revenue scenarios were considered with electric payment rates of $0.02 per kWh, $0.03 per kWh, and $0.04 per kWh. It should be noted that potential revenues for the electric generation scenarios would be much higher if the avoided cost of electricity were considered (at $.04260 to $0.13148 per kWh) rather than these utility payments, where avoided electricity is simply the amount generated onsite rather than purchased from the utility. The facility may generate its own electricity and sell electricity back to the utility, whether alternatingly or simultaneously.

In the scenarios where the facility is producing either compressed natural gas for transportation vehicles or delivering pipeline-quality gas to the natural gas distribution system, historic natural gas prices were used to determine avoided costs of fuel or potential revenue. Natural gas prices vary frequently and seasonally, and were an average $4.28 per thousand cubic feet (mcf) in 2017 and dipped to as low as $3.12 in May 2018.[32] For this study, natural gas prices of $3.00, $4.00 and $4.50 per mcf were used for the three yield/revenue scenarios.

When processing biogas to produce a compressed natural gas equivalent fuel, bio-CNG, the sale or use of this fuel in transportation may qualify for RIN credits under EPA's Renewable Fuel Standard.[33] Like any trading program credit, the value of RINs has fluctuated in recent years. This analysis assumes a baseline RIN credit value in line with historical averages at $0.80 per RIN (advanced biofuel gallon equivalent) and has a low-price case of $0.50 per RIN and a high-price case of $1.00 per RIN.[34]

Like RINs, the value of credits under California's LCFS can also fluctuate. In recent years, however, LCFS credit value has grown steadily to a current average price of about $177 per ton.[35] California LCFS credits are capped at a maximum price of $200 per ton. This analysis assumed a baseline price close to 2018 average prices at $170 per ton, with a low-end value of $150 per ton and a high-end value at the maximum $200 per ton.

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[32] "Minnesota Natural Gas Prices." 2018. U.S. Energy Information Administration, Independent Statistics & Analysis. U.S. Energy Information Administration. August 31, 2018. https://www.eia.gov/dnav/ng/ng_pri_sum_dcu_SMN_m.htm.

[33] "Approved Pathways for Renewable Fuel." 2018. United States Environmental Protection Agency. United States Environmental Protection Agency. September 5, 2018. https://www.epa.gov/renewable-fuel-standard-program/approved-pathways-renewable-fuel.

[34] "RIN Trades and Price Information." 2018. EPA. United States Environmental Protection Agency. September 20, 2018. https://www.epa.gov/fuels-registration-reporting-and-compliance-help/rin-trades-and-price-information.

[35] "Weekly LCFS Credit Transfer Activity Reports." 2018. California Air Resources Board. September 18, 2018. https://www.arb.ca.gov/fuels/lcfs/credit/lrtweeklycreditreports.htm.

Table 3. Revenue assumptions across three yield/revenue scenarios.

Input Assumption	Low	Expected	High	Units
Tipping Fee	$45	$58	$70	$/ton
Biogas Yield	2.16	3.5	3.5	MMBtu/ton
Gas Price	$3.00	$4.00	$4.50	$/mcf
RIN Price	$0.50	$0.80	$1.00	$/RIN
LCFS Price	$150	$170	$200	$/ton
Electricity	$0.02	$0.03	$0.04	$/kWh
MN Bioincentive	$2.1053	$2.1053	$2.1053	$/MMBtu

Source: Great Plains Institute, 2018.

To measure the economic potential of a range of possible scenarios, a series of yield and revenue cases were constructed for this analysis. A *low* case assumes a biogas yield of 2.16 MMBtu per ton, as presented in the 2016 UC Davis research assumptions, as well as declined market prices for the bioenergy products. An *expected* case uses mid-range or baseline prices for bioenergy products and a biogas yield of 3.5 MMBtu per ton, which is informed by the research conducted by Foth for Ramsey County/Washington County in 2013. Finally, a *high* scenario assumes a general growth in value for bioenergy products towards the higher prices seen in table 4, while using the expected yield from Foth. GPI did not find a basis in the literature search for using specific yields higher than the expected yield of 3.5 MMBtu per ton estimated for Ramsey County/Washington County organic waste by Foth.

Table 4. Annual net revenue and net revenue per MMBtu of biogas produced for 6 feedstock processing and biogas yield scenarios across yield and revenue sensitivities

Scenario		Net Revenue per MMBtu $ / MMBtu	Annual Net Revenue $ million
1a 50,000 tons *Biogas to Electricity*	Low	-$9.52	-$1.03
	Expected	$0.89	$0.16
	High	$5.59	$0.98
1b 50,000 tons *CNG Biogas: RFS Credit*	Low	-$17.18	-$1.86
	Expected	$1.76	$0.31
	High	$8.02	$1.40
1c 50,000 tons *Pipeline Biogas: RFS & LCFS Credits*	Low	-$5.24	-$0.57
	Expected	$17.41	$3.05
	High	$26.88	$4.70
2a 100,000 tons *Biogas to Electricity*	Low	-$1.52	-$0.33
	Expected	$5.83	$2.04
	High	$10.53	$3.68
2b 100,000 tons *CNG Biogas: RFS Credit*	Low	-$2.24	-$0.48
	Expected	$10.98	$3.84
	High	$17.24	$6.03
2c 100,000 tons *Pipeline Biogas: RFS & LCFS Credits*	Low	$6.76	$1.46
	Expected	$24.82	$8.69
	High	$34.29	$12.00

Note: Includes capital and operating costs.

Source: Great Plains Institute, 2018.

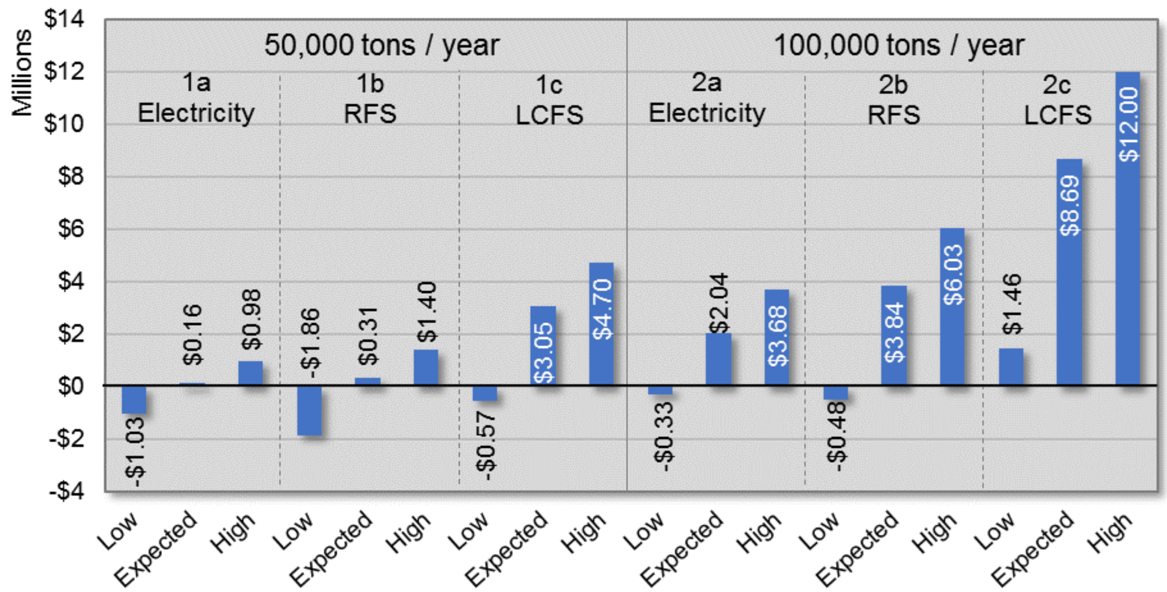
Resulting projected per-unit revenue rates and total annual net revenues vary both across processing volume scenarios and across revenue/yield cases. Due to projected prices, electric production scenarios result in the lowest revenue compared to bio-CNG and pipeline gas production scenarios. Low yield cases also produce significantly lower revenue than expected yield cases. The 100,000 TPY scenarios produce significantly greater revenues than the 50,000 TPY scenarios due to economies of scale for capital and operational costs and due to the sale of larger volumes of bioenergy product.

A facility that processes 50,000 TPY of MSW to generate electricity may generate approximately $0.89 per MMBtu sold in the expected yield case and as much as $5.59 per MMBtu in the high revenue case. However, in the low yield/revenue case, a 50,000 TPY facility that uses its biogas to make and sell electricity may incur a cost of $9.52 per MMBtu of biogas produced. Project economics improve at a greater waste processing volume of 100,000 TPY, incurring a lower cost of $1.52 per MMBtu produced in the low yield/revenue case while generating a net revenue of $5.83 per MMBtu in the expected yield and revenue case, and $10.53 in the high revenue case. Project economics improve at a greater waste processing volume of 100,000 TPY, incurring a lower cost of $1.52 per MMBtu produced in the low yield/revenue case, while generating a net revenue of $5.83 per MMBtu in the expected yield and revenue case, and $10.53 in the high-revenue case. Depending on the type of generator unit used for electricity production, this facility may produce 22 million to 44 million kWh per year in the expected yield case or 14 million to 27 million kWh per year in the low yield cases. See figure 5 for the resulting annual net revenue for all scenarios.

In the bio-CNG producing scenarios, a 50,000 TPY facility incurs a cost of $17.18 in the low yield, low revenue case but generates net revenues of $1.76 and $8.02 per MMBtu in the expected yield/revenue case and high revenue case, respectively. Again, project economics improve at the larger processing volume of 100,000 TPY, with lower costs of $2.24 per MMBtu incurred in the low yield, low revenue case, and higher net revenues of $10.98 per MMBtu in the expected yield and revenue case, and $17.24 per MMBtu in the high revenue case.

Finally, a facility that upgrades biogas to pipeline quality and gains access to credit trading under California's LCFS program generates positive revenue in five out of six scenarios. Only in the low yield, low revenue case at 50,000 TPY does the pipeline biogas scenario incur a net cost of $5.24 per MMBtu. In the expected yield and revenue case, this facility produces $17.41 per MMBtu in revenue at 50,000 TPY and $24.82 per MMBtu at 100,000 TPY. The high revenue case logically produces the greatest net income, generating $26.88 per MMBtu at 50,000 TPY and $34.29 per MMBtu at 100,000 TPY, which is the highest revenue-producing scenario found by this analysis. Figure 5 displays the projected net annual revenue for all scenarios.

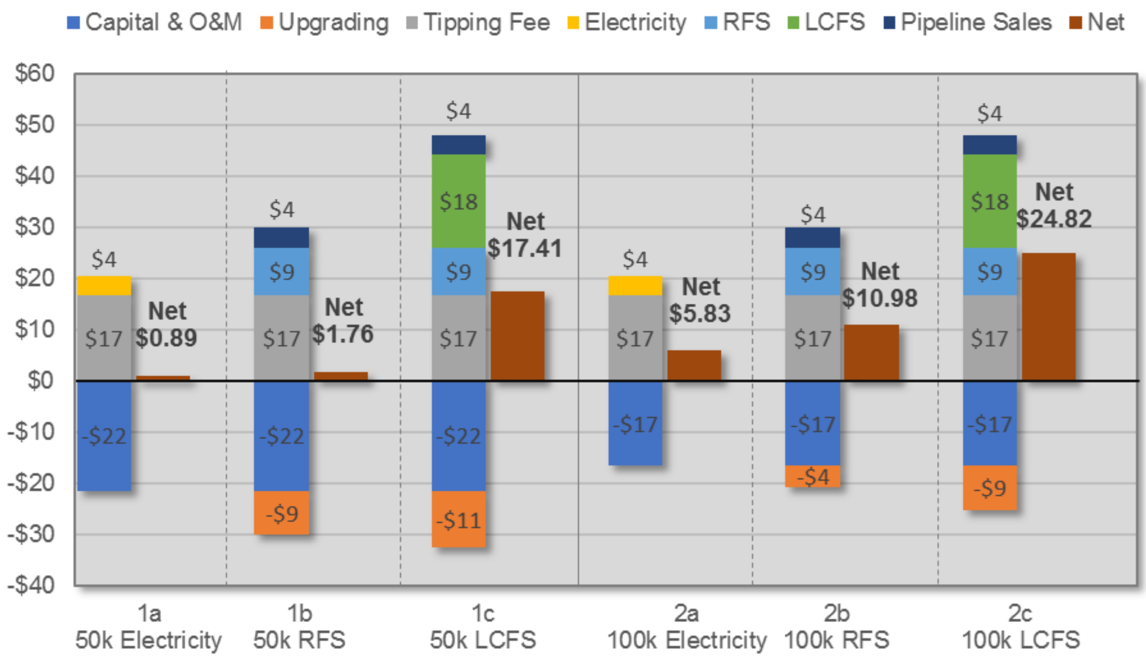
Figure 5. Annual net revenue ($ million) for 6 feedstock processing volume scenarios across biogas yield and revenue sensitivities



Source: Great Plains Institute, 2018

Figure 6 provides a detailed breakdown of cost and revenue components for the expected yield and revenue (baseline) case across all six processing volume scenarios. At expected yields and revenues, all six scenarios produce net positive revenue. Because fuel producers can earn both RFS RINs and LCFS credits simultaneously, the pipeline-quality gas (LCFS) scenarios produce more revenue than the bio-CNG scenarios in all cases.

Figure 6. Components of net revenue per biogas output ($ / MMBtu) for 6 processing volume scenarios with "expected" yield and revenue inputs

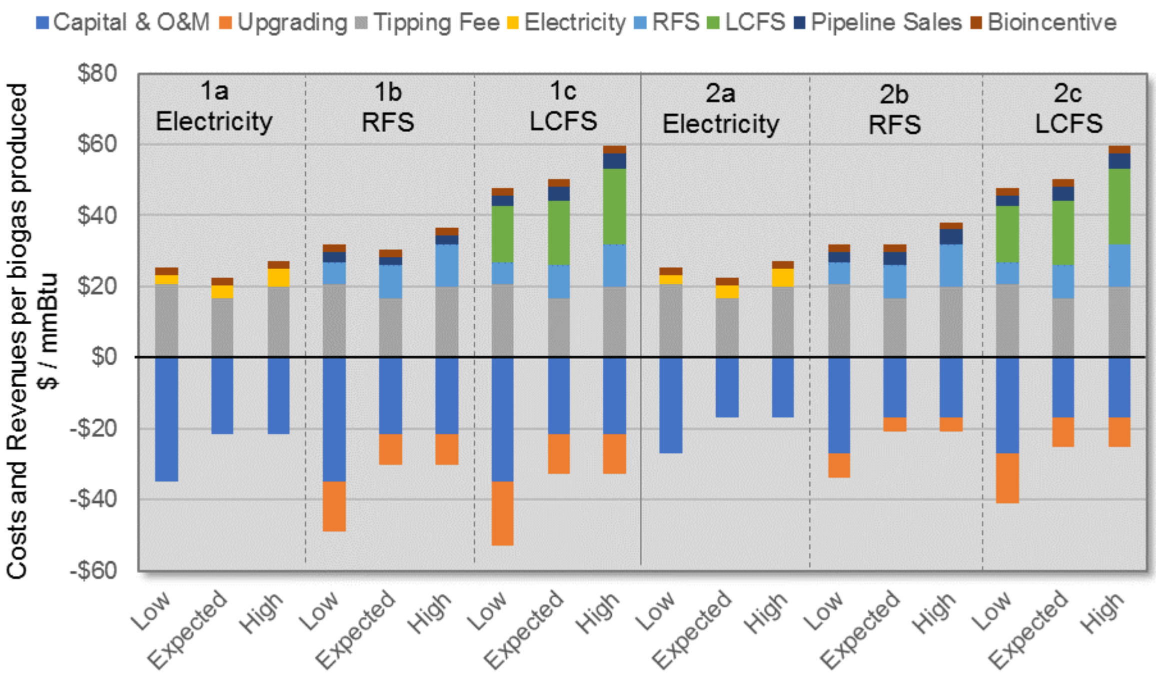


Source: Great Plains Institute, 2018

Figure 7 displays a cost and revenue breakdown by component for each scenario. Capital and operating costs are significant but do improve due to economies of scale for the 100,000 TPY scenarios (2a, 2b, and 2c). Upgrading costs are also very significant in the RFS and LCFS scenarios and should be addressed further in a future technical engineering study. Tipping fees are a major source of income across all scenarios and are often the largest source of income in some scenarios. Note that because tipping fees are based on waste volume or tonnage, not on the biogas yield, tipping fees appear to be greater *on a per MMBtu produced* basis in the lower yield cases due to a higher tonnage-to-energy yield ratio. While revenues from electricity production are significant, the potential revenue from RFS and LCFS credits is much higher at current credit values. Electricity production could produce higher revenues depending on negotiated rates as part of a power purchase agreement between the facility and the local electric utility. Finally, the Minnesota AGRI Bioincentive Program, while smaller than the other revenue sources, contributes positively to project economics across all scenarios.

Generating electricity from biogas may be the technically simplest application, but it also has the lowest potential revenue. Costs involved in upgrading biogas for use as CNG or to pipeline quality for use as a distributed natural gas equivalent are significant, and further study on technical and economic feasibility is recommended. Data from the California Air Resources Board shows that five projects are approved to provide CNG derived from AD systems, as well as over 50 projects supplying CNG from landfill gas. It is unclear from the data which projects are doing pipeline injection vs. using gas onsite. The Point Loma Wastewater RNG Project is also reported to pipeline inject.[36] However, potential access to renewable fuel credit trading programs makes the RFS and the LCFS scenarios the highest potential revenue-producing facility configurations.

Figure 7. Costs and Revenues per biogas output ($ / MMBtu) for 6 feedstock processing volume scenarios across biogas yield and revenue sensitivities



Note: Revenue is indicated above the zero line, and costs are indicated below the zero line.

Source: Great Plains Institute, 2018

[36]"Pipeline Injection of Biomethane in California." BioCycle. March 12, 2018. https://www.biocycle.net/2018/03/12/pipeline-injection-biomethane-california.

Greenhouse Gas Emissions

Biogas is expected to displace the use of conventional energy products in each scenario. Electricity-producing scenarios displace the equivalent energy amount of electricity from the distribution grid or local utility (Xcel Energy is assumed here for demonstration purposes). Emission factors from EPA's eGRID database[37] were used to calculate electric emission intensities based on electric fuel sources reported by the Midcontinent Independent System Operator (MISO) North[38] and Xcel Energy[39]. These emission factors are 509.8 grams greenhouse gas (GHG) emissions per kWh for MISO North, 362.4 g GHG per kWh for Xcel in 2017, and 218.1 g GHG per kWh for Xcel in 2022.

Bio-CNG production and use in transportation vehicles are assumed to displace diesel use in trucks or utility vehicles. Argonne's GREET lifecycle model was used to calculate an emission factor for conventional diesel in Minnesota at 115.3 kg GHG per MMBtu.[40] Upgrading to pipeline quality gas is assumed to displace average North American natural gas. According to the US Energy Information Administration, North American natural gas contains 53.1 kg GHG per MMBtu.[41]

The resulting displaced GHG emissions are presented on the following page in figure 8. Due to a projected decline in the use of fossil fuels for electric generation in both the MISO North region and Xcel's territory, displaced emissions from electric generation are expected to decline over time. In both the 50,000 TPY and 100,000 TPY scenarios, the displacement of diesel in transportation vehicles produces the greatest GHG benefit. This is followed by the displacement of grid electricity on the MISO North system, though this benefit is expected to decline over time and may even be less beneficial depending on the fuel mix of the local utility if that utility is considered for displacement rather than the grid. Upgrading to pipeline-quality biogas to displace conventional North American natural gas produces a GHG benefit that is greater than most electric scenarios, especially those based on cleaner electricity mixes.

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[37] "Emissions & Generation Resource Integrated Database (EGRID)." 2018. United States Environmental Protection Agency. February 15, 2018. https://www.epa.gov/energy/emissions-generation-resource-integrated-database-egrid.

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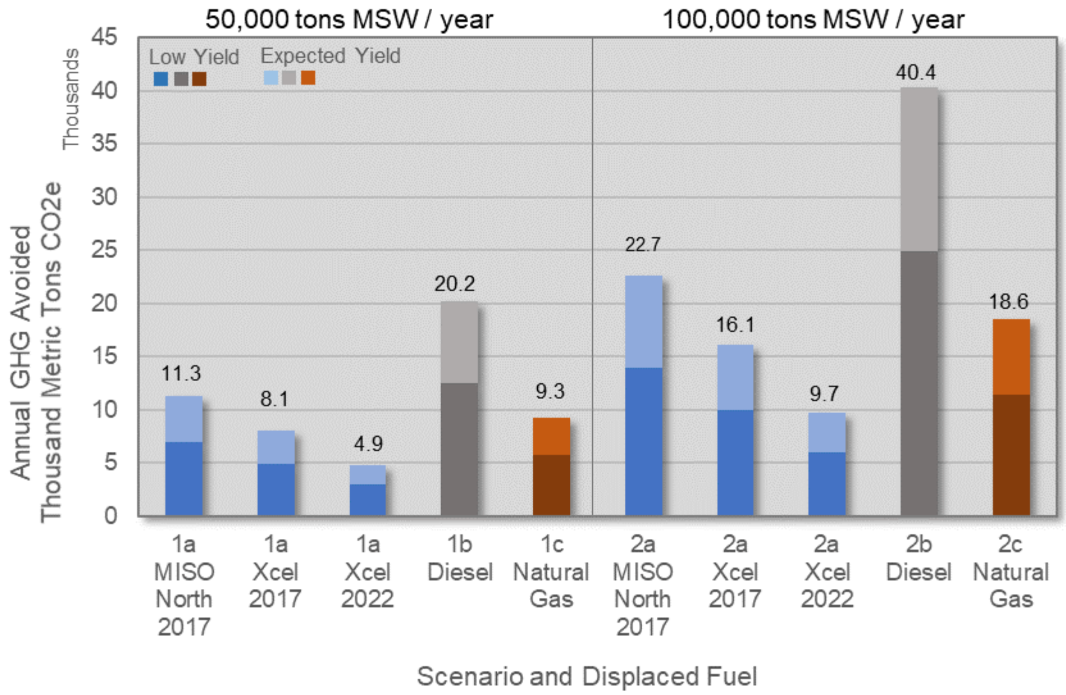
[40] "A fresh design for GREET life cycle analysis tool." 2017. Argonne National Laboratory Energy Systems. Argonne National Laboratory. October 9, 2017. https://greet.es.anl.gov/net.

[41] "Carbon Dioxide Emissions Coefficients." 2016. U.S. Energy Information Administration: Independent Statistics & Analysis. U.S. Energy Information Administration. February 2, 2016. https://www.eia.gov/environment/emissions/co2_vol_mass.php.

Figure 8. Avoided greenhouse gas emissions by scenario



Source: Great Plains Institute, 2018

Next Steps and Recommendations

PROJECT DESIGN CONSIDERATIONS

Technology Considerations. Research shows that a variety of technologies (dry vs. wet, thermophilic vs. mesophilic) have been used to process food waste and organic fractions of municipal solid waste and could be suitable for projects in Hennepin, Ramsey, and Washington counties. No clear technology pathway has emerged. Technology choice will depend in part on the composition of feedstock including the moisture content. Technology should be selected based on the likely feedstock available for the project.

European vs. North American considerations. Overall, there are more projects operating in Europe than the US that process municipal solid waste through anaerobic digestion and many successful US projects rely on European technology. Although the revenue environment in the US is very different from Europe, there are clearly lessons to be learned from Europe on how to reliably operate a project. European projects benefit from a supportive policy environment, high electricity prices because of feed-in tariffs, and ambitious energy, climate, and waste goals. US projects cannot expect the same sources of revenue as European projects. One task force participant reported risks of cost and reliability with bringing European technology to the US. The overall advice, however, from interviews and meetings of the Anaerobic Digestion Task Force, was to look closely at European technology and projects to benefit from the long experience and greater scale. A successful project is likely a hybrid, benefiting from superior European experience with technology and project operations, but relying on the US-focused (including Minnesota) evaluation of policy, regulation, and economic realities.

Source-separated vs. mechanically separated. Whether organics are source-separated or mechanically separated has implications for project design, but a clear favorite does not emerge from the literature. This choice will have cost implications for the project. There are clear economies of scale in operating a digester, and whatever organics-separation scheme is selected should achieve sufficient tonnage to allow the project to operate economically and reduce requirements for a subsidy. Contamination with non-organic materials is a concern for any project and can impact the ability to market digestate. Whether mechanical separation or source separation is selected, the digestate will have a higher value (or lower disposal cost) if contamination can be avoided or minimized.

Pre-treatment. Pre-treatment of waste prior to processing via anaerobic digestion can improve the overall reliability of the facility, reduce operational problems, increase yields, and impact the overall energy balance of the project. Pre-treatment can also increase overall biogas yields by, for example, reducing the size and increasing the surface area of materials, removing non-digestible materials, and liberating materials from compostable bags. A wide variety of pre-treatment technologies exist, including mechanical, thermal, chemical, and biological.[42]

Gas clean-up. Gas clean-up opens additional markets for biogas. A modest degree of gas clean-up allows for biogas use onsite for bio-CNG in vehicles and enables a project to generate revenue from the sale of renewable identification numbers through the federal Renewable Fuel Standard (RFS). Additional gas clean-up to pipeline quality allows for pipeline injection of "pipeline quality" biogas. This adds additional cost but allows the project to generate revenue from the California Low Carbon Fuel Standard (LCFS).

MARKET AND ECONOMIC CONSIDERATIONS

Economies of scale. There are clear economies of scale with anaerobic digestion systems. The counties should consider developing larger projects to improve overall project economics and reduce the need for high tipping fees. Another option to consider, like the CR&R project, is a modular approach that might start smaller and expand over time as additional organic waste becomes available.

Revenue from energy markets. Revenue from the sale of heat, electricity, or renewable natural gas (whether for vehicle fuel or pipeline quality gas) is a relatively small contributor to the revenues available to the project. It will be difficult for a project to break even economically (covering capital and operating costs with revenues) based only on revenues from energy markets, regardless of the energy product sold. It is possible, however, for a project to operate profitably relying on a combination of tipping fees and energy revenues under some scenarios, regardless of the energy market considered (for example, electricity, compressed natural gas).

Revenue from policy markets for fuels. Considerable opportunity is available through policy incentives for the sale of renewable natural gas into transportation markets. Incentives are available through the federal Renewable Fuel Standard, the California LCFS, and the state of Minnesota AGRI Bioincentive program. This introduces some risk, as credit values can fluctuate over time.

Revenue from policy markets for electricity and heat. The Minnesota AGRI Bioincentive program is also available for production of biomass thermal energy, but this incentive is smaller than LCFS and RFS incentives for fuel. Policy incentives from the generation of renewable electricity would not be significant, because the value of renewable electricity credits is driven by the low cost of utility-scale wind generation which operates are near or below the cost of average generation.

[42] Ariunbaatar, Javkhlan, Antonio Panico, Giovanni Esposito, Francesco Pirozzi, and Piet N.L. Lens. 2014. "Pre-Treatment Methods to Enhance Anaerobic Digestion of Organic Solid Waste." Applied Energy 123 (June): 143–56. https://doi.org/10.1016/j.apenergy.2014.02.035.

Revenue from tipping fees. Revenue from tipping fees is critical to the success of an anaerobic digestion project relying on municipal solid waste. Some project configurations can operate with positive economics relying only on tipping fees and revenues from energy markets. Tipping fees may offer more consistency than policy incentives which can vary unpredictably over the life of a project. At the same time, tipping fees can vary from county-to-county and there is a debate about what an appropriate tipping fee is for an anaerobic digestion project. Under some modeling scenarios, a project's capital and operating costs were covered by tipping fees alone.

Revenue from digestate. Digestate can be a source of revenue for anaerobic digestion projects or a source of cost from disposal. Some projects have looked at processing digestate to concentrate on nutrient products to increase the value. There is regulatory uncertainty about the ability to land-apply digestate. Possible contamination of the digestate would limit the ability to market it. Because of the uncertainty around the ability to sell digestate, we did not include it in the economic model. However, digestate management should be further evaluated to identify feasible options for turning digestate into a revenue stream rather than an ongoing cost.

Project ownership. The ownership model was not considered as a part of this analysis but can impact many aspects of the project. Ownership considerations can impact the availability of financing options for the project, the required rate-of-return, expectations regarding profit, the ability to cover project development costs, and the ability to secure a guaranteed supply of feedstock.

ENVIRONMENTAL CONSIDERATIONS

Disposal of wastewater and digestate. Disposal of wastewater and digestate is a complicated question and could ultimately add either cost or revenue to the project. If contamination of the feedstock can be avoided through source separated or mechanical separation of organics on the front end, then there are several end-markets for digestate, including the option to directly land-apply, to further process through composting to form higher-quality compost for sale, and to further process to develop higher-value products such as cattle bedding and concentrated nutrient products. Contaminated digestate will have more limited use and may incur cost rather than adding revenue. Depending on the type of contamination, some types of material can still be used as fill. Digestate may need to be disposed of in a landfill (although this will be significantly lower volume than the original organic material), which will incur a tipping fee and add cost to the project. Discussion in an Anaerobic Digestion Task Force meeting introduced the possible risk of per-and-polyfluoroalkyl substances (PFAS) as a possible contaminant in digestate. PFAS are emerging man-made chemicals of concern and could impact the ability to land-apply digestate. Likewise, wastewater may need to be discharged to a sanitary sewer, which will also add ongoing costs to a digestion operation. Hennepin County is completing a market study on digestate that could inform future project design considerations.

Avoiding odor. Odor considerations are often the driver behind public opposition to anaerobic digestion projects. Designing a project to limit odor is critical to the success of the project. Managing odor requires a comprehensive approach that includes evaluation of feedstocks, managing the receiving area, containing the digester within a building, managing emissions, air filtration, on-going monitoring, and other strategies. It is quite common for European projects to be located near population centers; closer investigation of European projects should be undertaken to gain an understanding of the effectiveness of their odor-control systems and the strategies and technologies deployed to control odor.

STRATEGIC PARTNERSHIPS

Feedstock partnerships. Because of the necessity of achieving scale to improve overall project economics, the counties should consider partnering with other feedstock suppliers to increase the overall supply of organics to a potential facility. Although the largest facility modeled here was a 100,000 ton per year plant, further returns to scale would be achieved with even larger projects, if other challenges could be overcome.

Utilities. Utility partnerships are critical for many project configurations. A project selling electricity will require a power purchase agreement. A project hoping to integrate renewable natural gas into the pipeline network will need to be sited in a location that offers access to an interstate pipeline and should avoid a long pipeline to the point of insertion to reduce costs. Discussions with either electric or gas utilities are critical and should commence as soon as possible.

Transportation. Partnering with a company that operates diesel vehicles or compressed natural gas vehicles could be a pathway to reduce gas clean-up by using gas locally for transportation. This strategy would allow the project to claim renewable fuel standard credits but not LCFS credits.

Policy and Regulatory. Early discussion with state, local, and federal government entities will improve the chances of project success. Minnesota Business First Stop can be a resource for understanding and communicating with all the state agencies that might be involved in permitting a project and helping to secure government incentives. There are various federal loan guarantee and grant programs and early discussions with USDA and DOE can help to identify and secure them. Discussions with local and county officials and local legislators will also be critical to project success.

Stakeholder engagement. Stakeholder engagement is planned as the next phase of this project. A range of stakeholders should be consulted to reach consensus on the role of anaerobic digestion in the future waste and energy systems in the Twin Cities metro area and develop recommendations on next steps.

FEEDSTOCK EVALUATION AND SUPPLY

Feedstocks and Project Design. An evaluation of available feedstock, decisions about which components of available waste to steer towards a potential project (e.g., yard waste), and decisions regarding mechanical separation vs. source separation will be central to the selection of technology and design of a project. Feedstock considerations will drive project economics and determine the selected technology, size of the project, and possible energy and digestate products. This includes consideration of possible feedstock augmentation and partnership with other feedstock suppliers. Where possible, augmentation with fats, oils, greases, and substance with high biogas potential can increase overall biogas yields from the project.

Feedstock reliability. Having a consistent and reliable supply of feedstock is essential for a viable project. Interruptions in feedstock supply would have a negative impact on project economics and cause reduced revenue without reducing capital and operating costs. Whatever technology, revenue model, and ownership structure decisions are made, a project must have a secure supply of feedstock.

Conclusion

GPI has gathered information on anaerobic digestion technology through literature review, expert elicitation interviews, the convening of an expert task force, and independent economic modeling. This project reveals that anaerobic digestion is an established technology for managing the organic fraction of municipal solid waste, with a particularly strong track record in Europe and with several notable projects in the US. We established that an anaerobic digestion project using municipal solid waste in the Twin Cities metro area could be economically viable under a variety of scenarios. Questions remain in a few areas, which are highlighted at the end of the report. Based on what we've learned, Hennepin, Ramsey, and Washington counties should continue to explore a possible project.

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