To Co-Digest or not to Co-Digest

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ABSTRACT

Based on a study conducted by EPA, municipal solid waste landfills accounted for 15% of total US methane emissions in 2018. Food and other organic material form the single largest category of waste directed to landfills. Many states are starting to recognize the impact of this practice on methane emissions and laying out plans to curb methane production in landfills.
Wastewater treatment plants that are equipped with means to process organic matter can offer a solution for a more concentrated and controllable production of methane gas and its subsequent reuse. Specifically, wastewater treatment plants equipped with anaerobic digesters are able to digest organic matter and generate methane in the process. The controlled approach of this digestion process also allows for proper collection, processing, treatment, and beneficial reuse of such gases.
This paper evaluates the landscape for the US, using available public data, to estimate available infrastructure that can accept diverted organic waste. Based on real-world examples, the analysis also evaluates required investment to capture this potential and the role that energy efficiency can play in justifying such investments. The analysis will also consider other strategies to increase biogas production from these facilities to make the return on investment attractive. Strategies such as chemically enhanced primary sedimentation not only reduces electricity consumption at a wastewater treatment plant but also increases biogas yield. Further, we will consider competing uses for this biogas for beneficial use. Finally, the analysis will show some economic trade off indicators as a function of energy retail rates.

Introduction

The Environmental Protection Agency (EPA)'s Landfill Methane Outreach Program (LMOP) works with more than 2,600 Municipal Solid Waste (MSW) landfills that are either "Open" or "Closed" status in the past few decades. "Open" landfills are currently accepting MSW. The database contains information for a majority of MSW landfills in the nation. It is not a complete database for every MSW landfill and does not contain information related to industrial landfills or hazardous waste landfills.
Based on available data (EPA 2021), across the US, daily volume of Landfill Gas (LFG) generated is estimated to be 2,363 million standard cubic feet per day (scfd). LFG is a gas that is generated during the decomposition of organic content in MSW. LFG is primarily composed of Methane and Carbon Dioxide. The Global Warming Potential (GWP_{100}) of Methane is at least 28 times higher than Carbon Dioxide (IPCC 2014).
In further analyzing data within LMOP's database, 34% of these landfills did not have any means for collecting LFG. For systems that were able to collect LFG, the daily average of 1,830 million scfd out of which 593 million scfd is flared. For systems that were equipped, the data set also reports out a percentage of methane content within the LFG. Average methane content across all such reported numbers is 48%.

Based on these numbers roughly about half (48%) of the generated LFG is not put to any beneficial use. If we consider landfills that are in “Closed” status, the total LFG generated on a daily basis is 2,987 million scfd with 2,230 million scfd captured and 776 million scfd flared. With this information, about 51% of the LFG generated is not put to any beneficial use. About 46% of these landfills do not have any LFG collection systems installed. The unused portion of LFG represents a heating value of approximately 7 million therms/day.
Reducing food waste in landfills can reduce generation of LFG since the organic content of MSW that is landfilled can be directly impacted. This is for landfills that are currently in “Open” status. Senate Bill 1383 (SB-1383 2016) was adopted in 2016 by California to reduce greenhouse gas emissions associated with methane production in landfills from organic matter decomposition. SB 1383 dictates specific paths and timelines to address this issue specifically related to organic matter disposal in landfills. Landfills alone account for 20% of methane emissions in the State of California. EPA estimates that in 2018, about 24% of the Municipal Solid Waste (MSW) generated and landfilled (EPA 2020) are food wastes. Food waste diversion to landfills remain the most commonly used means of disposal. All units in Table 1 below are in 1,000 tons.

Table 1: Food Waste Generation and Management (1,000 tons)

Year	**1960**	**1970**	**1980**	**1990**	**2000**	**2005**	**2010**	**2015**	**2017**	**2018**
Generation	12,200	12,800	13,000	23,860	30,700	32,930	35,740	39,730	40,670	63,130
Management Pathway										
Recycled	-	-	-	-	-	-	-	-	-	-
Composted	-	-	-	-	680	690	970	2,100	2,570	2,590
Other Food Management	-	-	-	-	-	-	-	-	-	17,710
Combustion with Energy Recovery	-	50	260	4,060	5,820	5,870	6,150	7,380	7,470	7,550
Landfilled	12,200	12,750	12,740	19,800	24,200	26,370	28,620	30,250	30,630	35,280

Per EPA (EPA 2020a), Industrial, Commercial and Institutional customers account for more than 75% of this waste generation with the remaining coming from the Residential sector. The two of the largest contributors to this waste are the Food Manufacturing/Processing and Hospitality Industries.
Food waste portion of the landfill accounts for 24% of the feedstock. Such wastes result in production of short-lived emissions which then have to be captured and disposed of properly.

Wastewater treatment plants (WWTP) that are equipped with means to process organic matter can offer a solution for a more concentrated and controllable production of methane gas and its subsequent beneficial reuse. Specifically, WWTPs equipped with anaerobic digesters are able to digest organic matter and generate methane in the process. The controlled approach of this digestion process also allows for proper collection, processing, treatment, and beneficial reuse of such gases.

The process of adding other organic material with municipal waste into anaerobic digesters is typically referred to as co-digestion. The organic material can be Fat, Oil or Grease (FOG) from local restaurants/kitchens or can be food waste, dairy waste, farm waste and other wastes that are organic in composition. Co-digestion results in higher gas yield from the participating digesters. As a general rule of thumb, the higher the fat content, the higher the gas yield. Gas generated in digesters in wastewater treatment plant is commonly referred to as Biogas/Biomethane. Biomethane is biogas that has been cleaned to meet utility natural gas pipeline quality standards. The first part of this paper analyzes the existing state of infrastructure available to receive and put biogas to beneficial use. The data used for this analysis is collected from various publicly available sources as noted below. The second part of the paper discusses a case study and competing use cases for biogas use.

Current state of market

Data Analysis and Quality Biogas generation, use and/or disposal has been addressed by wastewater treatment plants for decades. Water Environment Federation (WEF) has collected data on plants that have anaerobic digesters (WEF 2019). The database has identified 1,267 WWTP facilities throughout the US that use anaerobic digesters to process biosolids. These could be anaerobic digesters on-site at a wastewater treatment plant or a solids handling center where the facility receives and treats biosolids from a wastewater treatment plant.

The data provides information on plant's use of the generated biogas yield such as to drive machinery, electricity generation, injection into pipeline etc. This framework provides an important perspective into how biogas can be used beneficially at a site. Python programming was used extensively to collect data from WEF's website.

In order to verify the quality of the data utilized in the analysis of biogas production, the team cross referenced two sources of data from the EPA (EPA 2012) and the WEF. We wanted to compare the permitted design flow and average flow from the WEF database to the existing total flow and present design flows obtained from the EPA database. Based on the data obtained, a sample size was chosen to meet 90% confidence levels with 10% precision. The sample size was calculated using the following formula:

$$n_{sample} = \frac{t^2 \, x \, p \, x \left(\frac{1}{p}\right)}{d^2}$$

$$n_{finite} = \frac{n_{sample}}{\left(1 + \frac{n_{sample}}{n}\right)}$$

Where,

t = 1.645 (90% confidence level for a two-tailed t-test with infinite degrees of freedom)

p = expected percent of valid occurrences in the population (0.9)

d = desired level of accuracy (0.05)

n = population size

n_{sample} = required sample size without finite population correction

n_{finite} = required sample size with finite population correction

n_{finite} = 91

From a random number generator, 91 data samples were investigated of the 1,268 wastewater treatment facilities in the WEF database. Sixty seven percent (67%), or 61 of 91 data entries, matched between the WEF and EPA datasets. Thirty three percent (33%), or 30 of the 91 data entries, were inconclusive. Breaking down the discrepancies, 13 are caused by incomplete data from the WEF, 11 are due to incomplete data from the EPA, and 6 are a combination of both. Records in the WEF database that were missing data was backfilled using data from the EPA database.

Existing Use of Biogas For the purposes of this analysis, beneficial use is being broadly classified as direct use and indirect use for the purposes of this study. Direct use is the direct application of biogas in equipment such as engines used to drive machinery, digester heating or being injected into pipeline. Indirect use is where biogas is used to generate electricity. Biogas flaring is a special case since it does not represent a beneficial use of this resource other than ensuring complete combustion to reduce the GWP of the gas. Figure 1 below shows Direct use of biogas for various end uses.

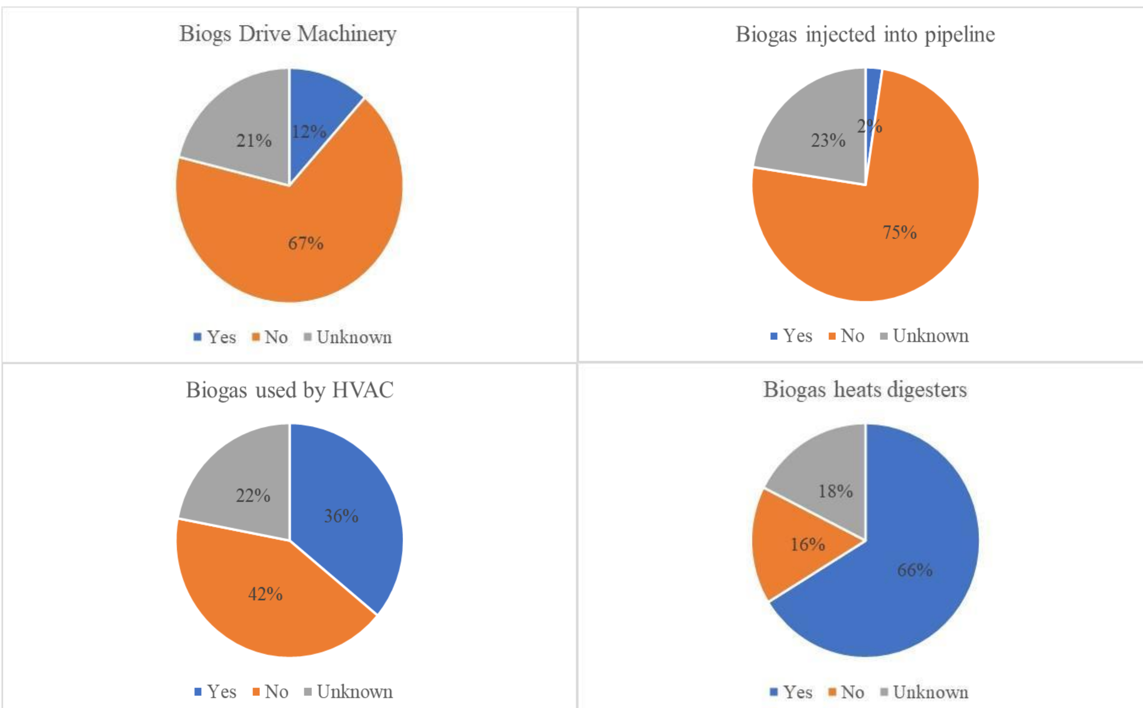

Figure 1. Direct Use of Biogas

The figure above provides direct beneficial use of biogas within the plants identified in the WEF database. Based on this data, biogas is mostly used to heat digesters. There is only a small percentage of plants that inject biogas into pipeline. Based on this database, there are 30 plants in the US that inject gas in the pipeline. The average reported influent flow for such plants is 40 million gallon per day which puts them on the higher end of size. The design capacity of these plants ranges from 4.2 to 450 MGD and average design capacity around 72 MGD and median design capacity at 31 MGD, which also means that size is not a restriction for plants to consider injecting Biogas into a utility pipeline.

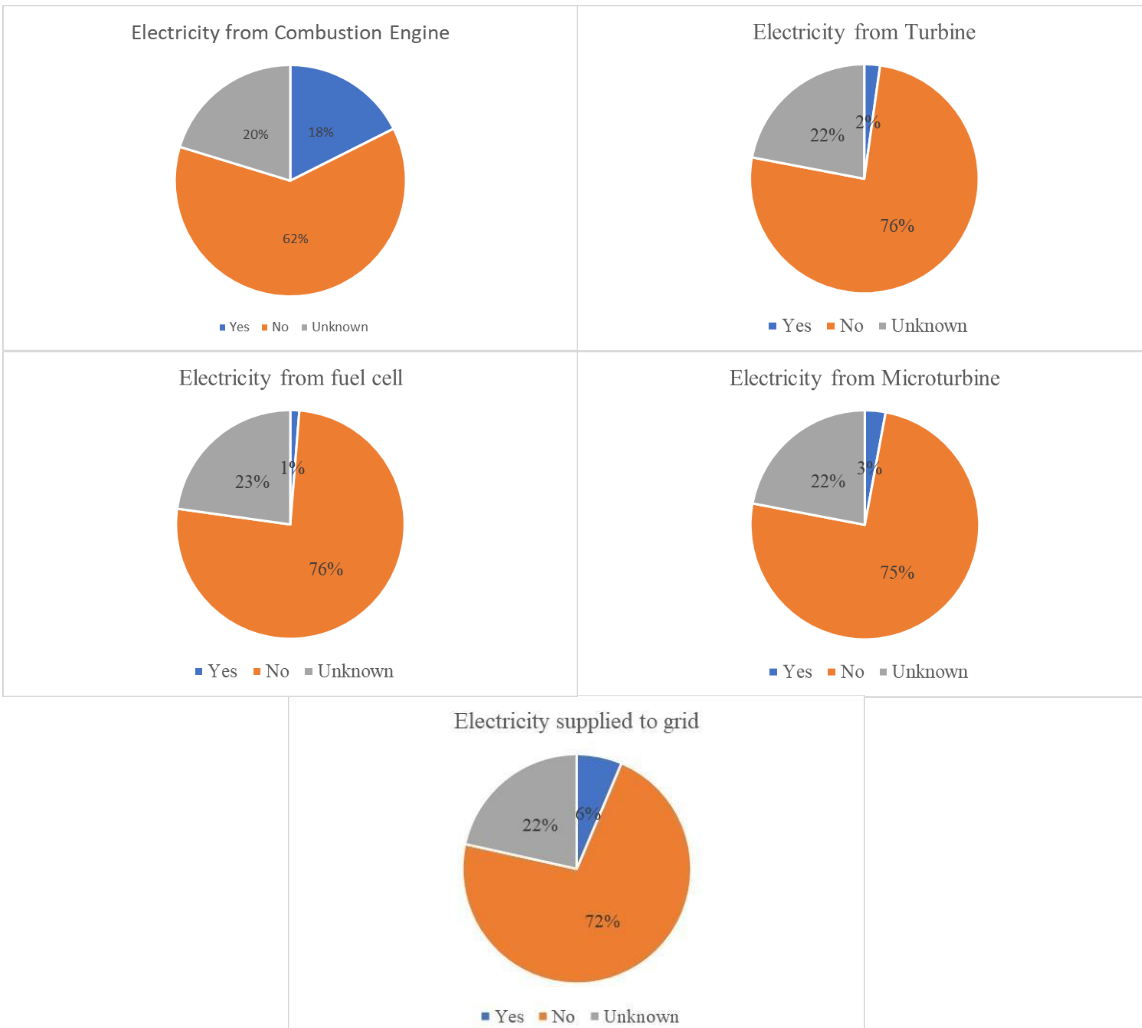

Figure 2. Indirect Use of Biogas

As can be seen above in Figure 2, electricity generation from biogas is not that common. There are multiple reasons for this including local air quality district rules which may limit operation of combustion engines used to generate electricity. This may also mean that the necessary personnel needed for the proper operation and maintenance of such electricity generating equipment may not be that common. This can be a significant barrier to adoption.

Rate Analysis (Electric) An analysis of industrial sector electricity price data by state sourced from the U.S. Energy Information Administration reveals a broad distribution of pricing trends. As of 2019, the average price per kilowatt hour of electricity purchased by industrial sector customers nationwide is 8.04¢. When weighted by average sector monthly electricity consumption by state, the price is slightly lower at 7.56¢, and the median price is 6.66¢. Some states with high average prices, such as Hawaii (25.8¢) and Alaska (16.9¢), have unique logistical challenges for electricity grid energy resources, driving prices to outlier levels. At the other end of the pricing spectrum, Washington (4.80¢), Oklahoma (5.07¢), and Louisiana (5.23¢) have abundant energy resources available within state borders. Hydroelectricity is responsible for 75% of Washington's electricity generation, the most of any state in the US (EIA 2021). Louisiana and Oklahoma are both top 5 in natural gas production nationwide, and natural gas is the largest electric generation resource in each state's grid profile (EIA 2021a; 2021b). Electricity prices shift over time, and 4-year pricing trends also demonstrate a wide range of variability by state and region. Weighted average changes in pricing from 2015-2019 are relatively low, only -1.33%, with a median shift of -1.20%. However, at either end of the distribution, the industrial sector in many states experienced significant shifts in pricing. Industrial electricity prices increased by more than 10% for 7 states, and decreased by more than 10% for 4 states (see Table 2 below). Evaluating the most cost-effective use of biogas generated at wastewater treatment facilities requires careful consideration of the value of either utilizing the resource on-site to offset retail energy purchases or exporting the fuel, as either electricity or pipeline-grade biogas, under available grid or natural gas system tariff structures. If electricity prices decline, non-electric applications for on-site biogas consumption such as heating or gas-powered drive trains may be economically preferable to cogeneration.

Table 2. States with Highest Price Shifts

State	Price Shift	State	Price Shift
Alaska	16.61%	Mississippi	-10.78%
Rhode Island	13.30%	Pennsylvania	-11.02%
Iowa	11.86%	New York	-11.04%
Hawaii	11.69%	New Mexico	-13.42%
Washington	10.45%		
Missouri	10.38%		

California	10.10%		

A key metric for forecasting the value of energy produced or consumed in the future is the escalation rate, or annual change in energy pricing. Escalation rates for electricity are essential to the development of a business case for on-site energy generation in any form, and these rates tend to track with longer-term energy price trends. A weighted average of annual escalation rates from 2015-2019 shows a mostly flat trend nationwide (-0.31%), further supported by the median value across states (-0.18%). The high end of increasing escalation rates tops out at nearly 4% for Alaska, followed by several states with escalation rates hovering around the 3% mark. At the other end, several states have escalation rates below -2.5%, including New Mexico (-3.41%), Pennsylvania (-2.84%), and New York (-2.83%). Declining escalation rates may limit the long-term value proposition of increased biogas production for on-site electrical generation. Figure 3 below shows a 5-year trend of electricity prices in the U.S.

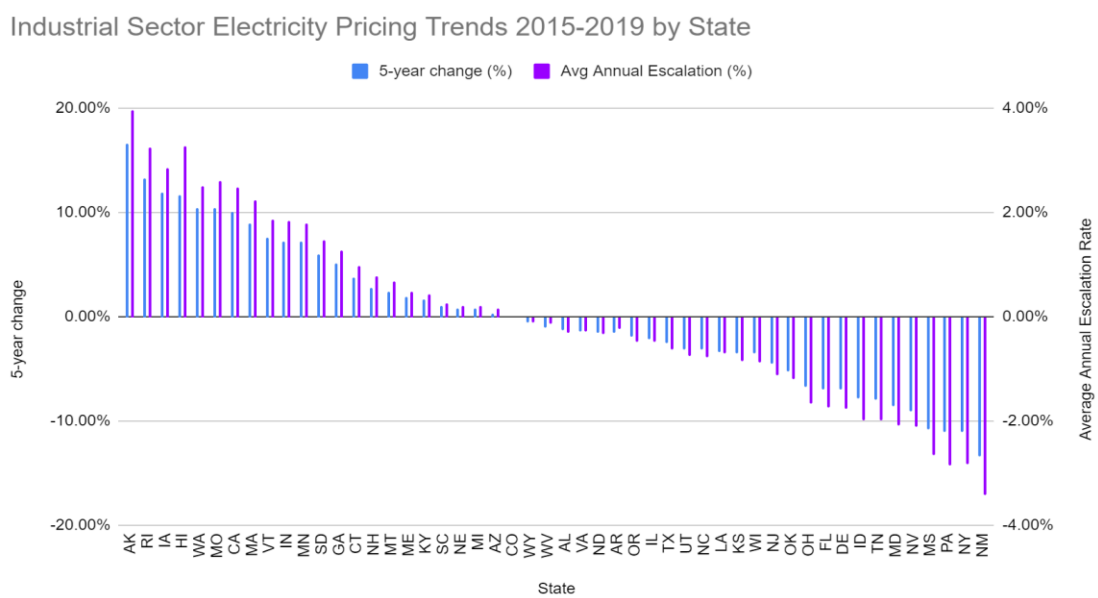

Figure 3. Industrial Sector Electricity Price Trends

Rate Analysis (Gas) A similar analysis on the price of natural gas (NG)for industrial sector showed a general downward trend in prices except for a select few states between 2015-2019 (EIA 2021c). The average price of NG has dropped slightly during this 5-year period. The weighted average price also followed a similar trend. On an absolute scale, there are 17 states that supply NG to industrial customers at rates higher than $0.60/therm which is the average retail price for the sector. The weighted average based on consumption (EIA 2021d) is $0.48/therm. This means that there is a significant price difference between different states. The average of retail prices when the average is lower than or equal to $0.6/therm is $0.45/therm. Conversely, the average retail price for states that have prices greater than $0.6/therm is

$0.88/therm. As with the electric prices, the cost of natural gas will play a significant role in justifying the business case of a codigestion project.

The remaining portion of this paper evaluates different scenarios that can play out in evaluation of a codigestion project considering all the aspects we discussed till now. The proximity of landfills to wastewater treatment plants, redundant capacity, available food waste that can be diverted from landfills to wastewater treatment plants all play part in justifying or rejecting a codigestion project at a wastewater treatment plant.

For example, Figure 4 below shows the remaining capacity in a wastewater treatment plant and the distance to the closest landfill. The remaining capacity is 1- (average influent/design influent capacity). Generally, plants at the 30% level or higher will have the additional capacity to take in diverted waste. Wastewater treatment plants are usually located close to the territory that it serves. Diverted food waste will generate additional digested solids at the wastewater treatment plant which should then be disposed off and usually at a landfill. If the digested solids have to be hauled over large distances to a landfill, any gains in GHG reduction may be lost. This paper does not evaluate the maximum distance to a landfill from a WWTP after which the GHG advantages are lost. We will evaluate that in a future iteration of this study. However, we do want to mention this consideration while evaluating codigestion programs.

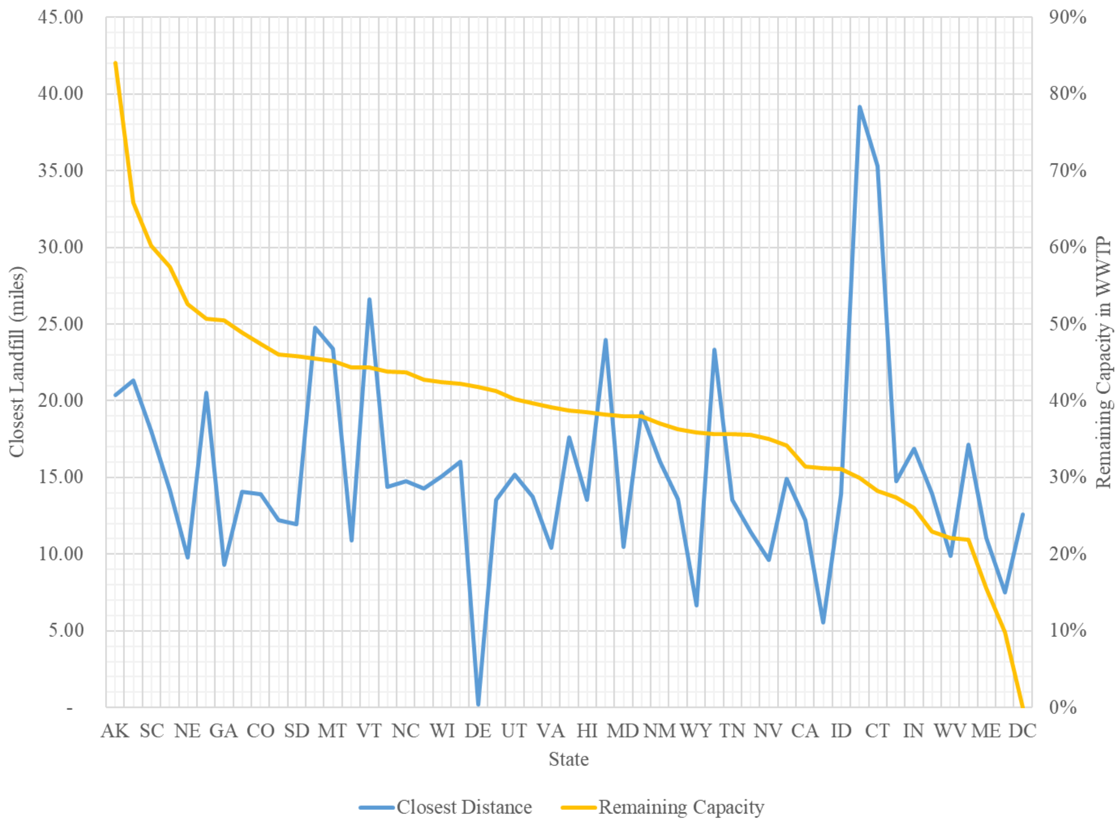

Figure 4. Existing Capacity and Closest Landfill

The LMOP database provided the coordinates of all landfills in the database. Using addresses provided in the WEF database, coordinates of WWTPs were determined using Google Maps Application Programming Interface and Python. Once the coordinates were determined, Python was used to calculate the distance from the WWTP to the closest landfill.

Economic Analysis

Codigestion requires additional equipment that is usually not part of regular process for a wastewater treatment plant. Cost considerations for this project was based on the EPA Food Water Biogas Economic Model. Some of the major ticket items in this list include an additional building, pre-processing equipment, pumping equipment, gas collection and scrubbing equipment, all the associated engineering design, permitting, cost of an additional anaerobic digester. It should be noted that the cost estimates here are high level and should be treated as a "Concept Screening". The final cost can vary significantly for each site depending on site specific conditions and should be evaluated independently. Therefore, these costs should only be considered as an indication of the required investment.

We are also not attempting to estimate the size or scale of the codigestion market vis-à-vis landfill diversion. This work has already been completed by others.

In addition to the initial investment, continuous investment is required as a part of regular operation and maintenance of installed equipment. The installed equipment will also require additional energy for their operations. For this specific example, we are assuming a CHP unit that provides power for operation of the wastewater treatment plant electrical machinery while supplying the heat required by anaerobic digesters.

Codigestion projects enable wastewater treatment plants to receive organic waste within their facilities. This can result in a revenue stream for the plant in the form of tipping fees. Conversely, codigestion projects in wastewater treatment plants also result in increased disposal costs due to the increase in digested solids. To keep the analysis simple, the power generation from additional gas yield is derated about 30% to account for cannibalistic loads and the revenue from tipping fees is fully discounted to account for additional O&M expenses and additional disposal costs. Further, any renewable credits are also not considered in our analysis.

The analysis further assumes that the wastewater treatment plant is borrowing money for installing the unit with a loan term of 15 years. The analysis looks at various interest rate scenarios. The analysis assumes a loan term of 15 years. Interest permutations ranging from 0%-5% APR were considered in the lifecycle cost analysis. The NPV hurdle rate for each analysis is assumed to be the same as the interest rate. Therefore, analysis at higher APR is burdened higher compared to lower APR.

It is to be noted that based on our estimates, the minimum threshold for entry is an investment of approximately $5 million dollars. To normalize the analysis, a benefit to cost ratio is considered rather than absolute costs and payback numbers. For the purposes of this paper, the benefit to cost ratio is the net present value of the investment over the life of the project divided by the initial cost. The life of the project is assumed to be 30years similar to the assumption used by EPA (Morellis et al. 2019).

Three approaches were considered in this analysis:

- Approach 1: Conservative outlook on the success of the program and assumes a 35% success rate which means that the codigestion plant is operating at 35% capacity.
- Approach 2: Assumes that the plant is operating at 67% capacity
- Approach 3: Aggressive approach assuming that the plant is operating at 100% capacity.

We evaluated these approaches for a scenario that looks at both electric power generation and heating using the additional biogas generated through the codigestion project. The assumed utility rates for this analysis are $0.0804/kWh and $0.59/therm. Figure 5 shows the results of this analysis for all three approaches.

If the benefit to cost ratio is negative, then it means that the project did not payback over its life. If the ratio is zero then it means that the benefits were exactly equal to the costs. If the ratio is greater than zero, then the project will yield more benefits than cost over the life of the project. A project can only be economically justified if the ratio is greater than or equal to zero.

Approach 1 is not cost effective under any of the permutations evaluated. This probably means that there is a minimum threshold for the amount of additional gas produced for projects like this to make economical sense. Since the amount of additional gas generated is a function of the feed that a digester receives, project success can be loosely correlated to the amount of organic waste that can be diverted.

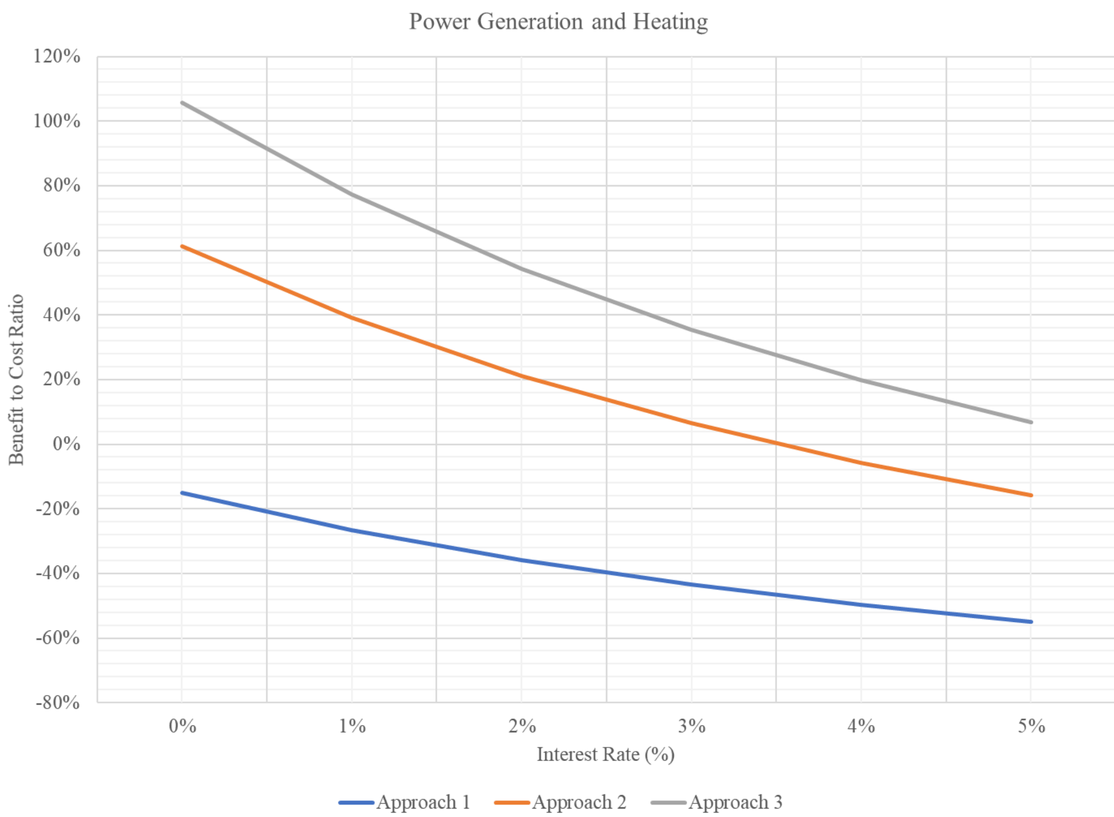

Figure 5. Benefit to Cost Ratio

We evaluated one additional scenario which assumes that all the additional biogas yield will be injected into a utility pipeline. In this scenario, the cost power generation equipment is discounted from the capital investment cost. This scenario evaluates Approach 2 and 3 under various gas rates. Similar to the previous scenario Approach 1 was only economical under two scenarios and as such those results are not presented here. Figure 6 presents results for Approach 3.

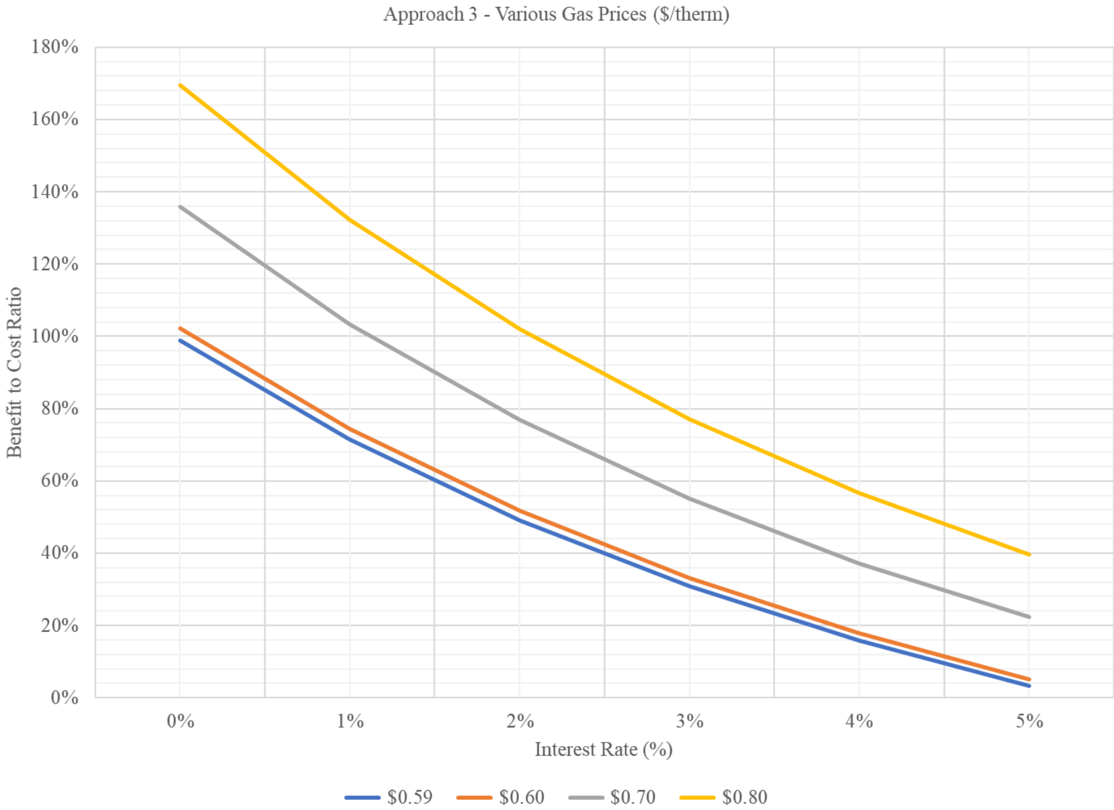

Figure 6. Benefit to Cost Ratio NG Only

As seen in the figure above Approach 3 is evaluated under various conditions for natural gas price. Price credits for RNG injection into utility pipeline may be negotiable. Therefore, it will benefit the wastewater treatment plant to understand the various scenarios under which a project can be justified. The current analysis does not consider any escalation in energy prices over the life of the project. This is in line with the 5-year trend of NG price that we discussed before. If a higher price cannot be negotiated, another option for the wastewater treatment plant is to factor in an escalation rate over the life of the project to justify the investment.

A similar analysis was completed for Approach 2 and the results are similar in trend, i.e. at lower interest rates and higher energy rates, projects are economical. Please refer to Figure 7 below for details.

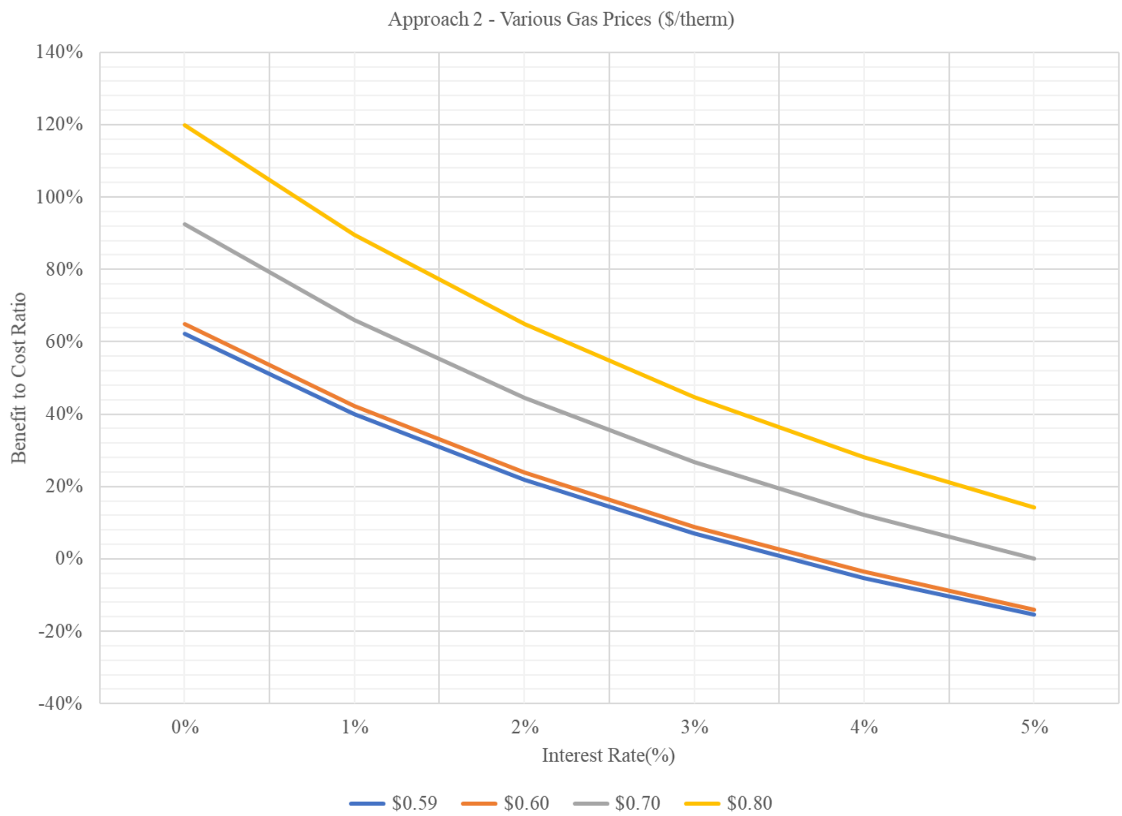

Figure 7. Benefit to Cost Ratio NG Only

Strategies such as Chemically Enhanced Primary Sedimentation (CEPS) have been shown to increase biogas yield. CEPS allows incoming Biological Oxygen Demand (BOD) in the influent sewage to settle out in the primary basins rather than be treated in the more energy intensive secondary basins.

This allows BOD to be repositioned into anaerobic digesters through primary sludge. CEPS may allow projects that were previously not cost effective to be justified with some additional investment. This strategy needs to be evaluated carefully based on requirements of the plant's influent loads, nutrient needs, process needs and cost. There will be first times costs related to installation of dosing equipment, any mixing equipment as necessary, and recurring costs with equipment upkeep as well as chemical costs.

Conclusion

Codigestion remains a promising and achievable solution for addressing a portion of emissions related to landfill gas generation. However, there are significant barriers to adoption as shown in this paper. Access to available technology, plant personnel that is trained on technology, proximity to landfills, available capacity in existing wastewater treatment plants all remain challenges to the adoption of this technology.

Flat trends in energy prices and the relatively low energy price enjoyed by industrial customers also means that it is harder to justify a codigestion project for a wastewater treatment plant.

Based on the analysis performed here, codigestion projects require strategies that will ensure codigestion plants are operating at as high capacities as possible to increase chances of success. This will require intervention at the local level to raise awareness in the program to ensure that the public participates in the program. Source separation of organics will also ensure that the wastewater treatment plants are receiving high quality substrates that ensure continuous operation. A participating agency will have to provide additional support to ensure that the public is educated and are good participants. Additional sources of organic substrates such as livestock waste, fat, oil and grease from local restaurants, institutional food waste, agricultural crop waste, waste from industrial scale food processing operations may be pursued increase gas yield.

The analysis also shows that participating agencies may require financial support in the form of incentives or low-interest programs to offset the cost of investing in codigestion.

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