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A brief research review on the anaerobic digestion of food waste

Setting the ground work for pilot testing

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ABSTRACT

The increase in regulations in certain state and local governments is requiring landfills to divert organic material to other more environmentally sustainable options is creating markets for the reuse of this organic material before it can enter local landfills. According to the EPA the anaerobic digestion of food waste (ADFW) is the only carbon negative process when dealing with the post-consumer use of food waste. Other landfill diversion options exist for food waste, composting and animal feed programs are popular, however the ADFW is the most sustainable option, potentially has as a rapid return on investment[1] while increasing biogas production that in turn can be used to increase local energy that can be used in a variety of ways. Wastewater treatment plants that have anaerobic digesters can take advantage of these regulations to supplement their feed stock for their anaerobic digestion (AD) system. Food waste can increase the performance of anaerobic digesters while also increasing their biogas production. That increase in biogas can then augment a fuel supply needs for other systems at those wastewater treatment plants or the could export that energy to the open market in form of electricity or compressed natural gas.

I have been in the wastewater business for 20 years and in that time I have been part of the great Fats Oils and Grease (FOG) digestion revolution, the ability to make digester gas (biogas) from bacon and other grease and oils. Every major plant was looking to build a FOG receiving station and generate revenue by charging a tipping fee and creating more biogas. This turned out to be a bust for many in the wastewater industry. This market was quickly taken over when

[1] ROI is based on local energy cost and capital costs associated with pre-processing of food waste prior to the introduction of that food waste to the anaerobic digester (AD) system. This assumes that no or minimal capital investment is needed for the AD system located at WWTPs using food waste.

the biofuel revolution came to maturity, specifically making biodiesel from cooking oil and other high-grade oils used in commercial settings. This loss of FOG to the biofuels market is now being replaced by food waste in far greater and more reliably quantities. Wastewater treatment plants are now partnering with local Material Recovery Facilities (MRF) part of the Municipal Solid Waste (MSW) collection and disposal industry to use processed food waste mash to feed anaerobic digesters that convert that mash into biogas to fuel Combined Heat and Power (CHP) or other energy systems. There is great concern that the use of food waste at wastewater treatment plants could go the way of the FOG revolution. The handling, processing and carbon negative status of large volumes of food waste is making the appeal of using existing anaerobic digester infrastructure and excess digestion capacity at wastewater treatment plants more appealing for some regional solutions to solve some of the organic waste diversion requirements.

INTRODUCTION

In environmentally progressive states like California the impact of relatively recent regulations like *SB-1383 Short-lived climate pollutants: methane emissions: dairy and livestock: organic waste: landfills*. (State of California Legislature, 2016) and *AB 1826, Chesbro. Solid waste: organic waste.* (State of California Legislature, 2017), both are associated with the diversion of organic material from lands fill is presenting a set of challenges and opportunities to address anthropogenic impacts of being a prosperous nation. Organic waste, specifically food scraps that end up in landfills can break down under anaerobic conditions into carbon dioxide, water, methane and other byproducts (Xua, Lia, Gea, Yangd, & Lia, 2018). When methane gas escapes to the atmosphere it becomes part of a greater problem. Greenhouse gas (GHG) production is a real and persistent problem responsible for the gradual warming of the planet. Regulations in certain states now require cities to progressively minimize the chances of GHG production and part of these reduction strategies scientists and politicians have concluded that keeping organic material from entering landfills (State of California Legislature, 2016) can have a significant positive impact by reducing the formation of GHGs being emitted from landfills , specifically methane (CH_4), a GHG that is 28X more powerful that CO and landfills emit over 14% of all methane emissions (EPA, 2017).

Landfills are also highly regulated in many states making them expensive to operate and maintain. Approximately 16-17% of the volume of landfill material is in the form of food waste (CalRecycle, 2019). This significant mass also displaces volume that could be used for items that can not be reused in any way decreasing the useful life of landfill disposal sites. As landfills fill up they eventually close requiring locally generated MSW to transported even further away using even more fuel to transport MSW to landfill sites that are even further from city centers, the locations where most of the MSW is generated.

Wastewater treatment plants that have anaerobic digestion (AD) capacity can assist the MSW industry and their obligation to divert organic material from landfills by accepting processed food waste to be use as a feed stock for the AD system (Xua, Lia, Gea, Yangd, & Lia, 2018). Anaerobic digestion at wastewater treatment plants are industrial processes using large cylindrical tanks (typically) that hold a high concentration biosolids (Greene, 2015). These biosolids are microbial populations that allow the hydrolysis process to occur. Hydrolysis is the breakdown of complex organic material into simpler organic material that can be utilized by specific types of microorganism populations like acid form bacterial and methane forming bacteria (Xua, Lia, Gea, Yangd, & Lia, 2018). Anaerobic digesters use large mixing pumps to circulate the contents and ensure that all the microorganisms have an equal chance of getting some food (Greene, 2015). In addition to the constant mixing anaerobic digesters are also kept at a specific temperature range. The two ranges are Mesophilic, ~35^{o}C and Thermophilic. ~50 ^{o}C with a range of +/- 2-3 ^{o}C (Peck, 2008). The higher temperature range typically has better digestion results however the cost to keep digester hotter is expensive and can be a diminished return[2]. The last major system on anaerobic digesters is the biogas removal system. Methane is explosive because of its wide range of flammability. Digesters need to have many protective systems in place to ensure that the gas does not escape and safety devices such as pressure relief/vacuum devices are installed as well as flame arrestors (Greene, 2015). Think of anaerobic

[2] Thermophilic systems are used when space limited and building more digester capacity is challenging and expensive. Some wastewater treatment plants have waste heat that can be used to change their digestion systems from meso to thermophilic.

digesters are like your own stomach, it likes food, it breaks down that food into simpler forms for your body to use and occasionally you make a little gas too. In the case of wastewater treatment plants and their AD systems, they try to make as much biogas as possible.

Processed food waste ends up as pulp called mash (Gertman & Pellegrini, 2016), with a consistency like a baby food, that concentrates the food waste into a relatively easily handled product that can be transported, stored and fed into anaerobic digesters without noticeably impacting the hydraulic detention time of the digestion treatment process. Processed food waste has two products, the mash and the screened-out material that still requires disposal. This disposal of screened material is easier once processed as most of the water has been removed and this material has been compacted. This results in a more easily disposed of product that can be combined with green waste for composting.

Food waste mash is high in total solids, the amount of solids material in proportion to water content and extremely high in volatile solids, organic material in proportion to the amount of total solids, the material that is easily converted into other substrates (food for microorganism). This power packed food mash is a superfood for anaerobic digesters. The more of this superfood you feed to a digester the more digester (biogas) gas that it will produce. There are limits, however maximizing the use of this superfood to make as much biogas as possible without upsetting the treatment process has compounding treatment and economic benefits for the MRF, their residents and business they serve and can offset the fuel/energy requirements required to run WWTPs that have AD systems.

PROJECT STATEMENT & APPROACH

This brief but focused research on the anaerobic digestion of food waste is to confirm the use of food waste as a viable feed stock for anaerobic digestion at wastewater treatment plants to increase the production of biogas. If the available research demonstrates that WWTP that have excess treatment capacity will not be overloaded by the introduction of food waste, then development of a pilot test work plant should be the next step. The additional biogas production from the introduction of food waste to an AD system can be used in boiler systems, creating heat for HVAC purposes, used a fuel for engine generators or doing both in Combined Heat and Power (CHP) systems (Goldstein, 2018).

The organic diversion requirement in the state of California is forcing all MRFs to increase how it source separates organic material, especially food waste, to ensure they are meeting their regulatory diversion obligations and taking advantage of available markets. This paper assumes that all MRFs are meeting their tiered separation requirements for organics from the MSW stream annually (State of California Legislature, 2017) and that the source separated organics that this paper is concerned with is in the form of food waste. This paper also assumes that some sort of pre-processing of the source separated food waste will occur at these MRF locations. This is the most efficient practice as the amount of hauling is reduced and clean food waste mash is more marketable and requires less hauling than a contaminated food waste stream that still requires more processing. Lastly, this paper assumes more food waste is available then there are places that can accept it. This means the agencies that are required to collect the food waste, the MRFs, also need to pay to dispose of it.

Based on these assumptions this paper will focus on the use of food waste in the form of a mash that can be introduced to anaerobic digesters located at wastewater treatment plants for generating more biogas to be used to offset operating costs and in some cases, generate revenue from the sale of exceeds energy.

LITERATURE REVIEW

The white papers, reports, related regulations, presentations and other information provided information related to the some of the laws driving organic diversion from landfills and how a pre-processed food waste product can be used as a feed stock for AD. In California, a leader in environmental action, the organic food waste diversion legislation is a significant step towards sustainable and economically desirable practices. The diversion targets established by AB 1826 and SB 1383 require residents and businesses in the state of California to keep organic material from entering landfills ultimately decomposing and releasing methane gas, a powerful green house gas, to the atmosphere instead of being captured and used as an energy source for other systems (CalRecycle, 2019).

Source separated food waste can come from many places like grocery stores, food manufacturing, breweries, schools and company cafeterias and more. Food waste is also being separated in residential collection systems, using a trash receptacle that is has a small partition for food waste or a free-standing food waste container for routine collection with curb side waste pickup (State of California Legislature, 2016). The amount of available food waste is impressive and according to figure 1 there are millions of tons available for anaerobic digestion however only a small fraction, less than 2% (Xua, Lia, Gea, Yangd, & Lia, 2018), of that food waste is actually being use for ADFW.

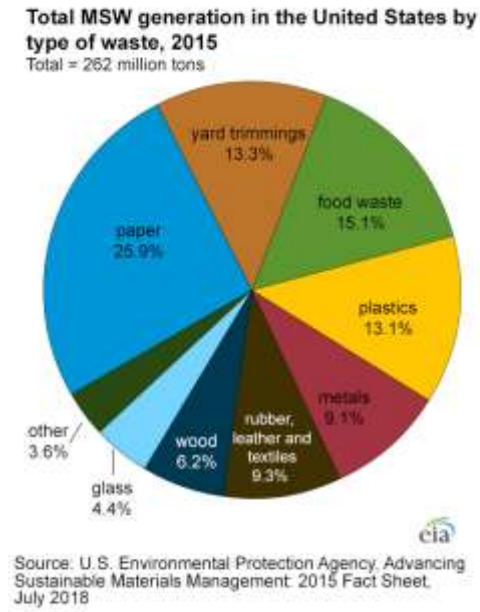

Figure 1

Once the food waste has been collected it is taken to a location for pre-processing (Greene, 2015), converted into mash before it can be fed into a digester. The reason pre-processing need to happen is that food waste is often contaminated with bags, containers, utensils and more that take up space, damage equipment and do not digest (Peck, 2008).

Food mash is concentrated volatile solids that is easily degraded by the organisms inside anaerobic digesters (Xua, Lia, Gea, Yangd, & Lia, 2018). To put this into perspective most wastewater treatment plants pump a sludge to digestion at a concentration of less than 5% solids with 75-80% of those total solids being volatile solids. Food mash can range from 10-30% solids with nearly all of it, 95% or more being volatile solids. This significant increase in VS means this food mash is ready to digest, there is nothing to stop it from being rapidly converted into Volatile Fatty Acids (VFA) a critical part of the Hydrolysis process (Xua, Lia, Gea, Yangd, & Lia, 2018).

The amount of food waste that any anaerobic digester system can handle is limited by a number of operating parameters. The mechanical, biological and other related AD systems have a design capacity directly related to a specific anaerobic digester design. All anaerobic digester systems are limited to handle a certain amount of hydraulic throughput and organic loading (Xua, Lia, Gea, Yangd, & Lia, 2018). At wastewater treatment plants that use anaerobic digestion of raw sludge and waste activated sludge those digestion systems can be limited by one or more of these system capacities.

Hydraulic detention time directly impacts the ability for a digester to operate efficiently and meet regulatory obligations for disposal for treated biosolids. If the feed solids do not stay in the AD process long enough volatile solids destruction will not be as efficient as having the solids remain in the process for a longer amount of time (Peck, 2008). The decrease in VS destruction efficiencies also reduce the amount of biogas produced per pound of VS sent to the AD system essentially not getting as much biogas out of the process as possible. Lastly, disposal options become very limited if minimum time and temperature requirements of those solids inside the anaerobic digestion system are not sustained (Peck, 2008).

Volatile Solids Destruction in pounds and the associated Volatile Solids Reduction (VSR) Ratio, a special calculation for digestion, are the two critical data points that help determine the ongoing heath of the anaerobic digester system (Peck, 2008). When operating a digester with food waste being the primary feed stock there are concerns that ammonia inhibition can occur when the VS loading rate becomes to great (Xua, Lia, Gea, Yangd, & Lia, 2018). Co-digestion of food waste solves this problem and improves the overall digestion process by buffering the rapid acidification that can occur when heavily loading a digester with food waste (Xua, Lia, Gea, Yangd, & Lia, 2018).

Operators that control the anaerobic digestion process at WWTP typically use a ratio of volatile acids to alkalinity (buffer – calcium carbonate) to monitor digester health. Normal VA/A ratios are between 0.1-0.2 (Peck, 2008). However when adding food waste to co-digest this ratio has been as high as 0.5 without any impacts to the digestion process (Peck, 2008). This not to say that every digestion system will be able to achieve the same result. Most WWTP will not and anyone who is considering using processed food waste to feed an AD system should be VERY cautious with any feed strategy when first introducing food waste to a system. The ADFW is happening at some WWTP with little to no issues and those plants are benefiting from increased biogas production.

SIGNIFICANCE and POLICY/BUSINESS IMPLICATIONS

The research supports that food waste is a viable feed stock for anaerobic digesters. There is clear evidence that food waste is more easily converted into small chain organics to be utilized by acid forming bacteria then by gas forming bacteria than conventional wastewater sludges (Xua, Lia, Gea, Yangd, & Lia, 2018). The hydrolysis process taking place in anaerobic digesters is limited when anaerobic digester are only fed raw sludges derived from convention wastewater treatment (Peck, 2008). By adding food waste the research demonstrates that the entire AD process is improved and more biogas is generated.

If a MRF is City/district owned and that city/district also has a wastewater treatment plant with excess anaerobic digestion capacity that city/district should perform a feasibility analysis to determine if processed food waste as a feed stock for their AD system is a viable economic option. If the feasibility analysis demonstrates a return on investment, then measures to conducted a pilot test to feed pre-processed food waste to the AD system should be developed.

MRFs that can partner with WWTP can decrease costs, keep organic material out of the landfills and potentially do this with minimal capitol investment.

CONCLUSIONS

Laws, regulations and economics is driving the diversion of organic material away from landfill disposal and into other, more sustainable, use and disposal options. The anaerobic digestion process at WWTPs, if underutilized, can be a method of beneficial reuse of food waste allowing those WWTPs to make more biogas to offset purchased power costs and improve the actual digestion process at the same time.

The available research clearly supports such use at WWTP when excess digestion capacity is available. If WWTP can successfully pilot test the ADFW in conjunction with their current operations, they will able to reduce the amount of biosolids produced by increasing the volatile solids destruction efficiency resulting in less costs associated with handling and disposal of treated biosolids. WWTPs will also be able to increase the production of biogas produced in their anaerobic digesters decreasing the cost associated with the purchase of natural gas to fuel their combined heat and power system.

ADFW only solves a part of the regulatory requirement to divert organic material away from landfills however it does this in one of the most sustainable methods. WWTP across California should begin to assess their current AD capacity and if there is room then plant for a pilot test to feed processed food waste to their anaerobic digestion system.

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