The Anaerobic Digestion of Organic Municipal Solid Waste in California.

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1. Introduction

With dwindling fuel sources and growing concerns about climate change, pursuing alternative and renewable energy has become imperative from both practical and ethical standpoints. Biofuels in particular have been touted as sustainable, more efficient, and cleaner sources of energy. While they should not be considered a panacea to all problems related to conventional fuel use, these energy alternatives could provide a number of benefits, including reducing the United States' dependence on foreign oil, lowering carbon emissions, and improving air quality. Despite the many advantages involved, however, many biofuel technologies continue to face a number of barriers to their expansion and commercialization.

Anaerobic digestion (AD) of organic municipal solid waste and subsequent biogas and methane production is just one of the many renewable energy alternatives out there. Defined as the digestion of carbon-based substances by microorganisms in environments lacking oxygen, anaerobic digestion already occurs naturally in landfills that contain organic waste, such as food scraps, paper products, and yard trimmings. One of the main products of this process is methane. As a result, landfills are the third largest source anthropogenic methane emissions in the U.S. Methane that is not captured or burned off ends up contributing significantly to the warming of the climate, an impact that is almost 20 times that of carbon dioxide when compared on a pound for pound basis over a 100-year timescale (Inventory of US Greenhouse Gas Emissions and Sinks, 2013).

Diverting organic waste to facilities that contain AD technology could greatly maximize the efficiency of methane production for potential energy use, simultaneously lowering greenhouse gas emissions from landfills. Additionally, this diversion could result in better landfill management, reducing tipping fees for businesses and addressing odor control issues.

Anaerobic digestion technology is attractive because of its role in organic waste management and climate change mitigating potential as well as biomethane production; by emphasizing these benefits and implementing certain policies, expanding and commercializing this technology in the state of California can be made more feasible.

2. Current status of AD technology

Anaerobic digestion (AD) of organic municipal solid waste (MSW) is a simple and proven biochemical process that has the potential to greatly impact today's climate change mitigation efforts, while producing a substantial volumes of biomethane for California.

2.1. Current Scale

According to the California Energy Commission, there are currently 22 operational anaerobic digestion facilities in the state that have a gross capacity of 5.7 MW (CA Energy Commission, 2013). When including the number of projects across various stages of development such as pilot, under construction or feasibility, the number of projects jumps to over 30. (Franco, 2013).

2.2. Feedstock

Anaerobic digestion works for many types of biomass feedstock including sewage, manure, forestry waste, agricultural waste (Rutledge, 2005). Based off of today's AD technology, the primary sources of biomass which we seek to utilize are the organic fraction of municipal solid waste from residential, commercial and industrial sources. Two examples of this feedstock include 1) food wastes from homes, businesses and food processing companies which end up at landfills, and 2) green waste such as grass, yard clippings, leaves which typically end up at either composting facilities or landfills (CEPA, 2012). As of 2010, 31 million tons of MSW were landfilled in California (Franco, 2013). Of this, 15.5% was food and 6% was leaves, grass and other organics. However, there are new developing technologies which are better at processing lignocellulosic biomass and would enable woody products such as lumber, paper and cardboard as additional sources of feedstock (Li et al., 2011). This would increase of the feedstock significantly, as woody products comprise another 35% mass volume of California's total MSW (Franco, 2013).

2.3. Collection & Sorting

The first steps for anaerobic digestion begin with collection of waste from residential, commercial and industrial sources. Organic waste diversion programs implemented by state and local agencies provide an initial separation of AD feedstock from other landfill waste. Community based residential waste collection programs can further ensure a steady and pure supply of feedstock (CEPA, 2012).

After MSW collection, the feed stock is loaded into a sorting system for mechanical biological treatment or MBT to remove any remaining impurities ("Briefing of Anaerobic Digestion", 2007). In an MBT facility, machinery is used to remove any non-biodegradable materials. This waste stream is further separated non-recyclable materials which are sent to landfills and recyclable materials such as metals, plastics and glass which are sent to recycling centers (Figure 1.). This reduces the volume of waste and makes it biologically inactive so it can be landfilled without releasing methane.

2.3.1. Waste Separation in California

Cities such as San Jose and Berkeley are striving to be "zero waste" and implementing comprehensive organic waste collection systems. San Jose plans to divert 80% of it's recyclable or organic waste from landfills into recycling or compost centers (White, 2011). StopWaste.Org is an Alameda County organization that seeks to divert over 75% of its food scraps and paper waste from the landfills into alternative processing facilities (StopWaste.org, 2013).

2.4. Biochemical Process

Anaerobic digestion is a biological process called biomethanation, or methane fermentation. The pH level and temperature should be kept between 5.5 and 8.5 and 30-60 C to maximize digestion rates ("Briefing", 2007). The amount of biogas and the quality of digestates obtained will vary according to the feedstock used. Biomethanation can be divided into four phases (Figure 1.):

- Hydrolysis: where complex organic molecules (cellulose, proteins and fats) are broken down into simple sugars, amino acids, and fatty acids by hydrolase, an exoenzyme. Hydrolysis of carbohydrates takes place within a few hours while proteins and lipids take a few days to break down.

- Acidogenesis: The monomers formed in the hydrolytic phase are taken up by acidogenic bacteria to be further degraded into short chain organic acids, alcohols, hydrogen and carbon dioxide.

- Acetogenesis: In this stage, acetogenic micro-organisms further breaks down the hydrogen and carbon dioxide gas to produce mainly acetic acid and organic acids and alcohols are converted into acetate. The acetate serves as a substrate for methane-forming bacteria and the acetogenic bacteria grow in a symbiotic relationship with methane forming bacteria.

- Methanogenesis: Lastly, bacteria called methanogen convert the acetic acid into methane, CO_2 and water under strict anaerobic conditions. Digestate is also a byproduct formed during this process (Chandra et al., 2012).

2.5 Types of AD systems.

There are 3 categories of AD systems: one-stage continuous including low-solid/"wet" and high-solid/"dry" ones, two-stage continuous represented by dry-wet and wet-wet systems and batch (either one-stage or two-stage) (Vandevivere et al., 2002).

Continuous processes reactors require waste input in regular intervals and an equivalent removal rate of similar output. This reactor type requires at minimum 20% solid material in the tank. Examples include the Valorga process, owned by Valorga international; the Kompogas process; and the Dranco process, which is marketed by Organic Waste Systems.

Batch systems make up a smaller portion of the marketplace than continuous process reactors and are better at processing lignocellulosic biomass. The biomass input can range from 30-40% total solids and is digested in a gas-tight container. Finished digestate is used to inoculate the dry stackable waste. The German company Bekon has the largest market share of batch digesters. Advantages include simplicity of the reactor, low maintenance requirement, and minimal capital cost (Li et al., 2011).

Single-stage digesters are simple to design, build, and operate and are generally less expensive. They represent about 90 percent of the installed AD capacity in Europe (Rapport et al., 2008). The organic loading rate of single-stage digesters depends on the the ability of methanogenic bacteria to tolerate the decline in pH that results from acid production during the hydrolysis step. Two-stage digesters separate the initial hydrolysis and acid-producing fermentation steps from methanogenesis allowing for higher loading rates, however, requiring additional reactors and handling systems.

Another important design parameter is the total ratio of solids to water in the prepared feedstock, which allows to classify one-stage continuous systems as high solids/"dry" or low solids/"wet". A prepared feedstock stream with less than 15 percent TS is considered wet and feedstocks with TS greater than 15-20 percent are considered dry. Due to water usage constraint, dry systems have become most common in Europe, making up 60 percent of the single-stage digester capacity installed (Rapport et al., 2008).

Drawing on the statistical data provided above, one-stage dry continuous AD systems are the most feasible for the organic MSW management. They constitute about 55% of the overall AD capacity in Europe. Therefore, that was the first and most successful, as of today, AD system brought to and adopted in California. The German Smartferm Technology is a good representation of the one-stage dry continuous system and being described in the case study of the paper.

2.6. End Use

Raw biogas is typically 60-70% methane and 30-40% carbon dioxide (Rutledge, 2005). Depending on the end use, the biogas can be "cleaned up" through a variety of processes to remove carbon dioxide and other contaminants, resulting in biomethane which can reach 99% methane. The two most common applications are combustion to generate heat and electricity or purified and compressed to be used as fuel.

2.6.1. Biogas

The biogas from an AD plant can be burnt in a combined heat and power (CHP) plant, generating renewable-only heating. Such AD/CHP plants are well suited for use in distributed generation schemes, where power and heat are generated more locally than in our current electricity supply system. Power capacities for typical AD/CHP plants range from 75KW-1.5MW.

2.6.2. Biomethane

Due to its purity, biomethane is essentially equivalent to natural gas and can be use in place of natural gas, including distributed to households or for natural gas vehicles. Both of these uses have their own set of gas standards to prevent the corrosion or degradation of equipment. To processes the biogas into biomethane takes considerable energy as well.

Anaerobic digestion also produces a solid and liquid residue called digestate which can be used as a soil conditioner to fertilize land.

2.7. Potential hazards

There are a number of potential hazards associated with anaerobic digesters. The most common are general safety practice precautions. These include hazards such as drowning in storage tanks, falls from high spaces, burns from hot equipment such as pipes or engines, exposure to high voltage and electrical fire. More specific to our process are the hazards associated with biogas (US EPA, 2011).

2.7.1. Asphyxia

Asphyxia occurs when the body suffers from a supply of oxygen. Asphyxiants are gases which prevent the uptake of oxygen into human cells. The resulting products of biogas from anaerobic digestion - mainly methane, carbon dioxide, hydrogen sulfide - are all asphyxiants. The potential for human asphyxia occurs when humans are exposed to these gases in confined spaces with limited ventilation. The Occupational Safety and Health Administration (OSHA) has determined atmospheric concentrations of these gases which pose an "immediate threat to life or would cause irreversible or delayed adverse health effects or would interfere with the individual's ability to escape from a dangerous atmosphere" (Occupational Safety and Health Administration (OSHA), 2008) which are listed below:

- Oxygen deficiency – less than 19.5 percent by volume air
- Carbon dioxide – more than 40,000 ppm
- Hydrogen sulfide – more than 100 ppm

Precautions such as placing warning signs in areas prone to biogas and wall mounted gas sensors help ensure worker safety.

2.7.2. Explosion

As the main component of biogas, methane has a high explosion potential. The upper and lower explosion limits help determine the range of concentrations that will produce a flash fire when an ignition source is present. The upper and lower explosion limits for methane are 5% and 15% by volume air, respectively (Linde Gas LLC, 1995).

2.7.3. Feedstock and Digestate Spills

Biomass spills have the potential for land, water and environmental contamination and should be treated as swiftly and safely as possible. The first step involves identifying and controlling the source of spillage. Next, isolating the spill will minimize contamination potential and help with site clean-up and restoration. Finally, the incident should be properly documented and state and local authorities should be notified (US EPA, 2011).

3. Advantages of AD

The primary benefit of anaerobic digestion of MSW is twofold: 1) to divert organic solid waste from municipal landfills, and 2) to mitigate climate change; energy production is only a secondary benefit while enhances the attractiveness of this technology.

3.1. MSW management

According to the EPA, in 2010, Americans generated about 250 million tons of trash (EPA, 2010). This trash, also referred to as municipal solid waste (MSW), is primarily composed of paper (28.5%) and yard trimmings and food scraps (27%), followed by plastics, metals, rubber, leather, textiles, wood, and other miscellaneous and non-hazardous materials. Generally, about half of this waste is managed through landfilling (EPA, 2004). By diverting these organic wastes to separate facilities, we are saving considerable space from landfills.

Besides saving space from landfills, there are additional MSW management benefits from anaerobic digestion. Naturally decomposition of waste causes odor and water pollution issues. The controlled process of anaerobic digestion reduces odor and liquid waste disposal problems (Anaerobic Digestion, 2013).

3.2. Climate change mitigation

Methane production from landfills has many climate change implications. Policies affecting this sector could substantially reduce the amount of radiative forcing caused by anthropogenic methane emissions. Estimating the amount of methane emissions from landfills has been difficult to accomplish. This number depends on a variety of factors, including per capita production rates of MSW, composition of waste, landfilling rates, oxidation rate within the landfill, and many other variables (IPCC, 1996).

3.2.1. Untreated landfills

Landfills account for 17.5% of the total methane emissions in the United States and are the largest man-made source of methane emissions in the U.S. (third largest source of methane emissions after leakage from natural gas production and enteric fermentation) (Overview of Greenhouse Gases, 2013). Methane comes from the decomposition of organic matter by bacteria under anaerobic conditions. Capturing the large amounts of methane emissions from these landfills presents a huge opportunity for both reducing GHGs in the atmosphere and energy generation. MSW generates roughly 11.6 Tg of methane, or 66.7 million metric Tons of carbon equivalent (MMTCE) eq per year (Inventory of US Greenhouse Gas Emissions and Sinks, 2013).

3.2.2. Impact by Anaerobic Digestion

The diversion of MSW from landfills to AD systems would result in GHG emissions reductions due to decreased landfill activity and use of biogenic methane instead of fossil fuel for electricity production. Nationwide AD systems are projected to reduce cumulative energy consumption by nearly 15 million TJ and reduce GHG emissions by 7.2 billion tons CO_2 equivalent, over a 50-year period (DiStefano and Belenky, 2009).

In another study, Matthew and Themelis (2007) estimated changes in methane emissions from landfills by looking at three different factors: recycling, waste-to-energy (WtE), and gas capture. Because this paper looks at methane as a fuel, we seek to use this study to determine what emissions reductions we can achieve with the use of different WtE scenarios. According to this study, around 4.7 to 6.4 teragrams (Tg) CH_4/year of emissions are avoided between 2000 and 2010 under all WtE scenarios. This range is promising considering that the US methane emissions were 11.6 Tg, as noted previously. That's a 41-55% reduction in methane emissions!

We must note that the scenario above includes all WtE technologies - beyond just anaerobic digestion. However, by implementing AD technology at the full scale waste-to-energy capacity can exert a major mitigating influence on potential future emissions from landfill waste. In other words, the climate change mitigation implications regarding the regulation and potential use of methane as an energy source are quite extensive.

3.3. Energy production

While the reason municipalities seek to implement AD technology is for energy production, it is important to note that anaerobic digestion cannot be used to replace traditional fossil fuels as United State's primary source of energy. If all of California's MSW were converted into electricity, it would have the capacity to produce 5% of the state's power demand (Franco, 2013).

In a study done by DiStefano and Belenky (2009), it was found that the annual 127 million ton of MSW landfilled in the United States could be biologically converted to 5.9 billion m^3 of methane. The 15 billion kWh/year of renewable energy released through the biodegradation process is estimated to satisfy the annual consumption of 1.3 million United States households (~1%).

4. Expansion and Commercialization

While anaerobic digestion has been successfully implemented in a few municipalities, this technology is still only emerging in California; studying today's successful facilities and learning from the law, policy and business barriers that affect this technology will be integral to achieve sustainable expansion and commercialization.

4.1. Environmental Law and Policy

Many aspects of this technology are easily incorporated into current municipalities due to existing infrastructure and government cooperation, thereby circumventing many of the policy and law barriers that other biofuels face. For example, the very first part of the lifecycle is to collect the food waste and green wastes. In California, there are already 53 food wastes collection programs (CARB, 2012). With established waste collection programs, little additional legislation or coordination with municipalities will be necessary to fully implement delivery of MSW for anaerobic digestion. Similarly, the production of biomethane after MSW transport will be minimally impacted by local and state policies. Anaerobic digesters are unlikely to be stand-alone buildings, but rather built onto existing facilities for waste treatment. Therefore land planning concerns and zoning policies should not affect the construction of anaerobic digesters, since they have already been addressed in the construction of the original waste treatment facility. Regarding end use, the resulting biomethane is typically recycled for onsite uses or, when processed properly, can be injected into current natural gas pipeline, thus also avoiding potential policy or law barriers during distribution. There are regulations that focus on solid waste disposal as a whole. One is the Solid Waste Disposal Act of 1976, also known as the Resources Conservation and Recovery Act (RCRA). The RCRA's main objectives are to protect human health and the environment and to conserve valuable energy and material resources. One of the ways the RCRA accomplishes these goals is by siting, monitoring and closing certain MSW landfills. The act also helps enforce guidelines for the collection of solid waste, transport, separation, recovery, and disposal. Another way is by requiring controls on the formation, storage and leakage of methane. This federal legislation is highly directed towards MSW in landfills and create many requirements and burdens for subsurface methane monitoring. By increasing the regulation of MSW landfills, AD technology would be more favorable for states and private waste management facilities. There are also regulations that oversee aspects of anaerobic digestion, such as California AB 1900. This bill put into law in September of 2012 requires the California Public Utilities Commission (CPUC) to develop standards for biomethane injection into current methane pipeline infrastructure by December 31, 2013 (ARB & OEHHA, 2012). One portion of the bill tasks the Office of Environmental Health Hazard Assessment (OEHHA) to compile a list of biogas constituents that pose a health risk and exceed concentrations of those constituents in natural gas. In the other portion of AB 1900, the California Air Resources Board (CARB) is to develop realistic exposure scenarios and identify associated health risks to gas users and utility workers. The next steps include finalizing a list of constituents of concern and to develop the health protective concentrations (ARB & OEHHA, 2013). From our review, however, there seem to be minimal public health and air quality risks that would disincentivize anaerobic digestion of organic MSW.

4.2. Current Toxicity Rules

The chemical we are "manufacturing" with our process is methane. Since methane is listed in EPA's Toxic Substances Control Act (TSCA) Chemical Substances Inventory, it is considered an "existing' chemical. Therefore, no pre-manufacture notice (PMN) is required.

Another issue that we have to consider is the use of microbes in our process. However, since we are using naturally occurring microorganisms in the breakdown of organic material to produce methane, we are not subject to any EPA regulation. More specifically, we are not using "new" microorganisms, defined by the EPA as those that are created by incorporating the genetic DNA from organisms from different genera, and also referred to as "intergeneric" microorganisms (Office of Science and Technology Policy, 1986).

4.3. Climate Change Policies

As previously mentioned, methane is over 20 times more potent than carbon dioxide emissions. As a result, landfill methane emissions, as the third largest anthropogenic source of emissions, represent a huge potential source of mitigation.

There appear to be a number of federal and state programs and policies that regulate and potentially encourage the use of AD technology under the climate change benefits it can offer.

One program is the US EPA's Landfill Methane Outreach Program (LMOP), which is a voluntary assistance program that encourages landfill gas (LFG) recovery and use. Joining LMOP allows companies, state agencies, organizations, landfills, and communities to gain access to a network of industry experts, practitioners, and technical and marketing resources that could help with LFG energy project development (EPA, Landfill Methane Outreach Program). While this program is wide in scope, it could potentially encourage landfills to divert organic waste streams for processing by AD facilities.

Another federal regulation falls under the 1996 Clean Air Act and is known as the "Landfill Gas Rule." This rule established New Source Performance Standards and Guidelines that require landfills with a 2.5 million metric ton design capacity that began accepting waste after November 8, 1987 to capture and burn landfill gas. The EPA has stated that while this regulation would only affect 5% of all landfills, it would reduce methane emissions by 37% and 39% at new and existing landfills, respectively (EPA, Landfill Gas Energy).

On the state level, there appear to be more policies that attempt to regulate methane emissions from landfills. For example, CARB implemented a regulation that became effective June 17, 2010 that is a "discrete early action greenhouse gas emission reduction measure" as characterized by the California Global Warming Solutions Act (also known as AB 32). The regulations requires that owners and operators of specific uncontrolled MSW landfills install gas collection and control systems, and also requires that already existing and newly installed gas and control systems operate optimally. The regulation also allows local air districts to participate in a voluntary memorandum of understanding (MOU) with CARB to implement and enforce the regulation and charge fees to cover costs (ARB, Landfill Methane Control Measure). Under AB 32, these landfill methane emission standards and regulations could help encourage a shift to AD technology use.

What are some policies that could potentially support this sector? Methane emissions from landfilling could be regulated under a varying suite of policies, including those relating to market-based approaches, carbon offsets or credits, emissions performance standards, and existing programs and incentives. Market-based mechanisms can be divided into two types: quantity control (e.g. cap-and-trade) and price control (e.g. carbon tax). Both of these would put a price on covered sources of methane emissions. In terms of carbon offsets, policymakers could encourage methane abatement as a possible offset project or as a credit in a greenhouse gas emission control program. This offset option would be attractive because it would possibly make an emissions program more cost-effective. Another policy option is through emission performance standards. Setting performance standards would require that a certain type of version of technology be used, thus increasing efficiency of that technology (Bracmort et al., 2009). What about existing policies? As mentioned above, a section of the 1996 Clean Air Act already has air emission standards on large landfills, but landfills smaller than the size specified under the Act are not covered. Expanding this section so that landfills of smaller size are included of the Clean Air Act could result in increased methane capture. Additionally, requiring landfills to divert biogas from landfills to power grids or other avenues that use methane as an energy source could increase the co-benefits achieved through both methane regulation and climate change mitigation.

Another policy falls under the California Renewable Portfolio Standard (RPS), in which 33% of California's total energy procurement must be from renewable energy standards by the year 2020. The RPS is jointly implemented by the California Public Utilities Commission

(CPUC) and the California Energy Council (CPUC, 2007). AD technology could help contribute to this goal.

4.4. Current Commercial Status

Several different anaerobic digester technologies are currently at various stages of the development process. One is the Smartferm system developed by Zero Waste Energy (ZWE), a company that designs, builds, and operates solid waste facilities across North America. The Smartferm system is a compact, semi-mobile dry fermentation plant. Based in California, ZWE has already initiated a number of projects in the state, all at varying levels of development. For example, the project in Marina-Monterey is currently under a five-year demonstration phase, with a larger system planned for the future (Projects of the Future). The project in Napa is currently in the initial stage of design and development. Solid waste and recycling companies in Alameda County are on the verge of commercializing their facilities. Another company, Clean World Partners (CWP), utilizes three different technologies: anaerobic phased solids (APS) digester system, dynamic biofilm reactor (DBR), and high-rate digestion (HRD). During June of 2012, CWP received a $6 million grant from the California Energy Commission (CEC) to increase its capacity at their Organic Waste Recycling Center in Gold River, California, resulting in the largest commercial high solids AD plant in the U.S. ("Clean World Partners Received $6 million grant").

4.5. Obstacles Regarding Commercialization

There are many obstacles faced by these technologies. The BioConverter digester, a single-stage, sequentially batched system, was one of the first full scale digesters that treated municipal food waste in the U.S. Unfortunately, it was shut down in early 1999 due to odor control issues (Rapport et al., 2008). More recently, in 2008, a composting facility in London called Orgaworld was fined due to odor issues (Pedro, 2012).

A case study from 2004 highlights other obstacles. In 2004, the installation of an anaerobic digester in Linn County, Iowa was found to be potentially financially viable, but ran into other problems. Siting and permitting were found to be the major inhibiting issues. A report on the facility found that federal programs were not likely to fund the project; project managers would need to pursue other avenues of finance. This was found to be a common problem for new and novel waste treatment technologies, which have to be approved by planning commissions that are in charge of mitigating public financial risk (Rapport et al., 2008).

4.5.1 Ways in Which to Overcome Various Obstacles.

Anaerobic digestion technology is much better established and more common in Europe than in the United States. Many countries of EU, such as Germany, Denmark, UK, found a successful public policy solution for further commercial development of AD technology. So, drawing on their experiences can help to identify important pieces of legislation. Landfill taxes, landfill bans and various separate collection systems for organic waste are essential elements of their public policy.

According to Guilford (2009), "successful government policy creates an artificial economy which is sufficiently stable to support long-term investment in technologies and innovation (which would otherwise be completely unaffordable) to accomplish the goals of the policy." The United States is only in the beginning of the creation of the "artificial economy", so many important pieces of legislation are missing for successful commercialization and integration of the AD into the American economy.

The concepts of "shared value" and "social responsibility" became very important in global entrepreneurship and business development last decade or two, so it should be paid close attention to while creating new pieces of commercial development legislature. According to Porter and Kramer (2011), "the concept of shared value can be defined as *policies and operating practices* that enhance the competitiveness of a company while simultaneously advancing the economic and social conditions in the communities in which it operates." They also argued that "the purpose of the corporation must be redefined as creating shared value, not just profit per se. This will drive the next wave of innovation and productivity growth in the global economy."

Anaerobic digestion technologies used for food waste disposal can be easily seen as a "socially responsible" subcategory of waste management industry. It uses organic waste as a feedstock reducing costs for landfill management, produces biogas, electricity, heat, fertilizers; doesn't interfere with the environment; and can pay for its own operating energy costs. However, the technology is not widely adopted in the US yet; various incentives or, the so-called "artificial economy," are needed to ensure further adoption of AD for organic waste disposal.

Public policies used for commercial development of AD can be roughly divided into two groups: the ones restricting competing technologies' usage, and the ones promoting namely AD technologies for waste disposal and biofuel production. The first group can be represented by various landfill bans (e.g. maximum percentage of organic waste content in the waste which goes to landfills), landfill taxes, more strict environmental regulations of other biofuel production processes, such as hazardous byproduct disposal, location restrictions, environmental/agricultural regulations of feedstock production, etc. These policies/regulations don't affect the AD technology commercialization directly but makes it more competitive compare to alternative technologies. The second group of policies and regulations focuses on creating awareness of the AD technology overall and its benefits, as well as eliminating of socioeconomic barriers for commercialization of the technology. This group can be further divided into subcategories related to different stages of the process; promotion of usage of its desired product/byproducts, promotion of separate collection of waste, i.e. better feedstock quality, and decrease of capital intensity of the process.

Promotion of usage of AD desired product/byproducts include tax breaks for biogas/renewable heat/fertilizers/renewable electricity usage, various educational programs for businesses and individuals, conferences and seminars for educational institutions, governmental and industry grants for R&D.

Promotion of separate collection of waste can help to minimize problems caused by having non-biodegradable materials in the feedstock, such as plastics and metals. Increased tipping fees for MSW collectors, development of new more efficient systems of separate waste collection, tax breaks for businesses and individuals for separate waste collection as well as education about its importance will provide AD facilities with higher quality feedstock.

The decrease of the capital intensity of the process can be achieved by increasing its efficiency, yield and minimizing handling costs. Such policies include subsidies for AD facilities for electrical grid usage, creating of cost-effective transportation solutions and on-site waste management protocols, development of a governmental federal loan fund for stimulating investments in the industry and intensive R&D for increased yield and efficiency.

Another way to promote commercialization of the AD technology for organic waste management and biogas production is development of various certifications to ensure environmental safety and economic efficiency of the AD facilities. Current certifications applicable to the process are ISCC EU Certification (International Sustainability and Carbon Certification) and Roundtable on Sustainable Biofuels (RSB) Certificate of Excellence for Biomass and Biofuels (ISCC, 2009; Roundtable on Sustainable Biofuels, 2009). These certificates allow increasing competitiveness of the AD process compare to alternatives emphasizing its biological, environmentally friendly nature.

By working together on lobbying beneficial bills and policies, various AD facilities and waste collecting businesses can speed up commercialization of the technology. These facilities should also work close with consumers, such as individual households, businesses and educational institutions, to ensure that importance of each individual decision for the industry overall. The consumers should understand their responsibility, benefits and role in the promoting of the AD technologies in their local neighborhoods and country overall.

4.6. Potential Funding Sources

Funding to implement anaerobic digesters has largely come from the government, both state and federal. At the federal level, there are two main sources of funding: Section 1603 grants from the US Treasury Department and the USDA's Rural Energy for America Program (REAP) (Greer, 2011). Section 1603 of the 2009 American Recovery and Reinvestment Act includes is known as Payments for Specified Energy Property in Lieu of Tax Credits. This program reimburses applicants, such as energy providers or waste management businesses, for a portion of the capital costs of "installing specified energy property used in a trade or business or for the production of income". By offering a cash grant in lieu of the tax credit, farmers, who would use AD technology for things like the processing of manure, are no longer confronted with cash flow issues to start these AD projects, and the government is removing the obstacle of high upfront purchasing and installing costs. The grants can foot up to 30 percent of the installation cost for projects that qualify for the federal business energy tax credits (ITC) or production tax credits (PTC) (Greer, 2011).

The United States Department of Agriculture has invested greatly in rural development by awarding grants, loan guarantees and financial assistance to farms and other rural businesses to partially fund commercial AD systems through the establishment of the Rural Energy for America Program (REAP). One component of REAP, the Renewable Energy System and Energy Efficiency Improvement Guaranteed Loan and Grant Program provides funds to rural small businesses for the specific purpose of purchasing, installing and constructing renewable energy systems (Rural Energy for America Program, 2013). This program expands the existing private credit structure by providing a credit enhancement via a loan guarantee. Since 2003, the USDA Rural Development has awarded over $40 million for the construction of AD systems (Funding Programs for Developing Anaerobic Digestions Systems, 2012). Grants can cover up to 25% of eligible project costs, but are capped at $500,000 (Greer, 2011); loan guarantees can cover up to 75% of eligible costs and are capped at $25 million. These funds however are distributed on a competitive basis. An independent consultant conducts a business level feasibility study to determine the project payback, electricity generated per dollar requested, system efficiency and overall betterment of the community. Since REAP is not specific to anaerobic digesters, a barrier to these funds is the competition against other energy forms such as geothermal, hydroelectric and solar.

At the state level, California's Low Carbon Fuel Standard (LCFS), which calls for a 10% reduction in carbon intensity of transportation fuels by 2020, will create a market for new fuels such as compressed natural gas (Low Carbon Fuel Standard, 2013). However, there are no direct funding opportunities to spur the construction of MSW digesters. Other states such as New York and Wisconsin have financial incentive programs similar to the REAP and Section 1603 federal programs which provide financial assistance to small businesses seeking to implement sustainable energy and anaerobic digestion (Greer, 2011).

The government programs mentioned above are all geared towards businesses that seek to construct anaerobic digesters. These grants however, do not apply towards technology companies such as ZWE that commercialize the biogas. Technology companies such as ZWE sell their services and expertise to businesses such as rural farms or and public utilities like the East Bay Municipal Utilities District.

Rural farms or wastewater management companies (the client) will hire the services of Zero Waste Energy (the vendor) to develop and implement an appropriate waste to methane system. The client then pays the vendor capital costs to construct the digester as well as a per kilowatt fee of energy generated through AD. In return, the client's waste is managed environmentally consciously and safely, and the client saves money on electricity. Rather than funding from the government, biogas firms such as Zero Waste Energy are typically funded through joint ventures. ZWE was a joint venture founded by Bulk handling Systems of Eugene, Oregon and Green Waste Recovery of San Jose, California (Organic Waste to CNG, 2011). Through the creation of these two established waste management firm, ZWE bypassed many obstacles such as fronting capital costs and establishing its own waste collection system.

4.7. Future Prospects

The Natural Resources Defense Council study estimated that the United States loses about 40% of its food sources to landfills due to wasteful habits and practices: "This not only means that Americans are throwing out the equivalent of $165 billion each year, but also that the uneaten food ends up rotting in landfills as the single largest component of U.S.municipal solid waste where it accounts for a large portion of U.S. methane emissions" (Gunders, 2012).

The US EPA estimated that the per capita production of municipal solid waste (MSW) to be at 2.1 kg/day with total annual MSW production at 254 million ton, including 35 million ton of food waste. Currently, about 54% of MSW is disposed in landfills across the United States.

Current situation with regard to energy production by the AD process can be represented by the following data based on year 2011:

- **176** digesters in operation
- **15** new digesters brought on line
- **541 million** kWh of energy generated
- **1.2 million** metric tons of CO_2e destroyed
- **301,000** metric tons of CO_2e avoided (US EPA, 2011)

For current legislature and policies preventing the AD technology from spreading, we were not able to identify many. Anaerobic digestion is a natural biological process, similar to facilitated composting. Feedstock, by-products and the desired product are exempt from current US EPA regulations. However, multiple changes in policies are needed to promote further AD adoption and development, such as:

- Decrease overall capital intensity of biogas production
    - Tax breaks and subsidies for households and businesses using biogas instead of conventional energy resources

  - Subsidies for AD companies to use electrical grid for electricity produced from biogas or pipeline for biogas itself
  - Create cost and fuel-effective transportation solutions to decrease maintenance cost
  - Design of effective handling protocol on the waste generation site
  - Establish a new collection scheme for household food waste emphasizing separation of organic and non-organic materials
  - Develop a special governmental loan fund to stimulate investments
  - Adapt a new type of dry AD facility which is efficient, very compact, semi-mobile and requires only 20 days to be set up (Hanson, 2013)
  - Revised Standard rule permits for AD facilities which can make granting of the permit easier and faster for those applicants who meet the standard rule
  - Carbon emissions taxes on landfills would improve the economics of the AD industry
- Promotion of biogas usage
  - Various federal and private grants for developing educational programs about benefits of the AD process over conventional fuels
  - Promote renewable heat usage which gets generated during the AD process
  - Electrical Vehicle promotion
  - Long-term local authority contract arrangements about implementing emerging and innovative resource efficient technologies
  - Include possible AD plants sites for local needs into a regular City Planning routine
- Decrease the amount of biodegradable MSW which goes to landfills
  - Set targets for the reduction for the biodegradable municipal waste going to landfills
  - Increase tipping fees for MSW collectors
  - Create strict technical requirements for organic waste and landfills
  - Develop a map of feedstock sites and already existing AD plants, as well as determine best sites for building new AD facilities
  - Develop a temporary storage facility for biodegradable MSW on the collection sites, such as containers used for collection and temporary storage of organic waste

    - Create and enforce a set of guidelines for public bodies and businesses making it a part of a lease contract

- Promote further basic and applied research to improve the AD process
    - Federal/private/corporate grants for research projects advancing the AD process
    - Develop new educational programs at secondary schools and higher education institutions in Green Chemistry, Green Energy, etc.
    - Develop more efficient techniques for capturing by-products of the process and using them for various purposes
    - Grants for improving electrical/biogas-based vehicles' efficiency

- Promote separate collection of MSW
    - Tax breaks and other economic incentives for companies to collect garbage separately
    - Develop pilot programs for large grocery store chains to collect MSW separately and overall development of business relationships with large food companies, seafood processors, restaurants, educational institutions, hospitals, solid waste trucking companies, etc.

5. Areas of Further Research.

Although AD technology presents many benefits, there are still a number of issues that could not be covered by the scope of this paper that must be addressed further. Addressing these issues could help prevent any obstacles that may crop up in the future, thus potentially maximizing the benefits that can be achieved through this technology.

The paper is focused mostly on the Zero Waste Energy Company and its projects. However, there are many more companies involved in the Anaerobic Digestion industry in California and the US overall. Different companies might have different approaches to adoption and further development of the technology. Exploring them and learning the most successful strategies will help to find the unique way of integrating the AD technology in the economic, political and social sectors of the United States.

There could be other potential environmental and health hazards of the AD technology not covered in the paper. Depending on the initial content of the feedstock, the digestate and other by-products of the process may contain heavy metals, plastics and other inorganic materials that would need further treatment before safely introducing them to the environment, e.g. sending to landfills. Another potential health and/or environmental hazards may be brought by introduction of genetically modified organisms to increase yield and efficiency of the process. Released to the environment, the organisms can cause devastating consequences, such as reduction in natural species diversity due to increased competition. While encouraging further adoption of the AD technology, significant research funds should be directed towards exploring these issues.

According to our process description and diagram (Figure 1), better sorting of feedstock should yield less hazardous output. However, it's not clear if this is an assumption or a proven fact. More research is needed to eliminate uncertainties.

6. Conclusion

Anaerobic digestion of organic municipal solid waste has already been shown to provide a number of benefits, both fiscal and otherwise. Some of these benefits include organic waste management and climate change mitigation, with a secondary benefit methane production and utilization. Additionally, there appear to be little to no adverse public health and environmental effects of this technology and process, although we would recommend that this be looked into more in-depth, particularly if this technology were to be expanded across the state of California. Expanding and commercializing facilities that utilize AD technology could maximize these benefits.

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Appendices.

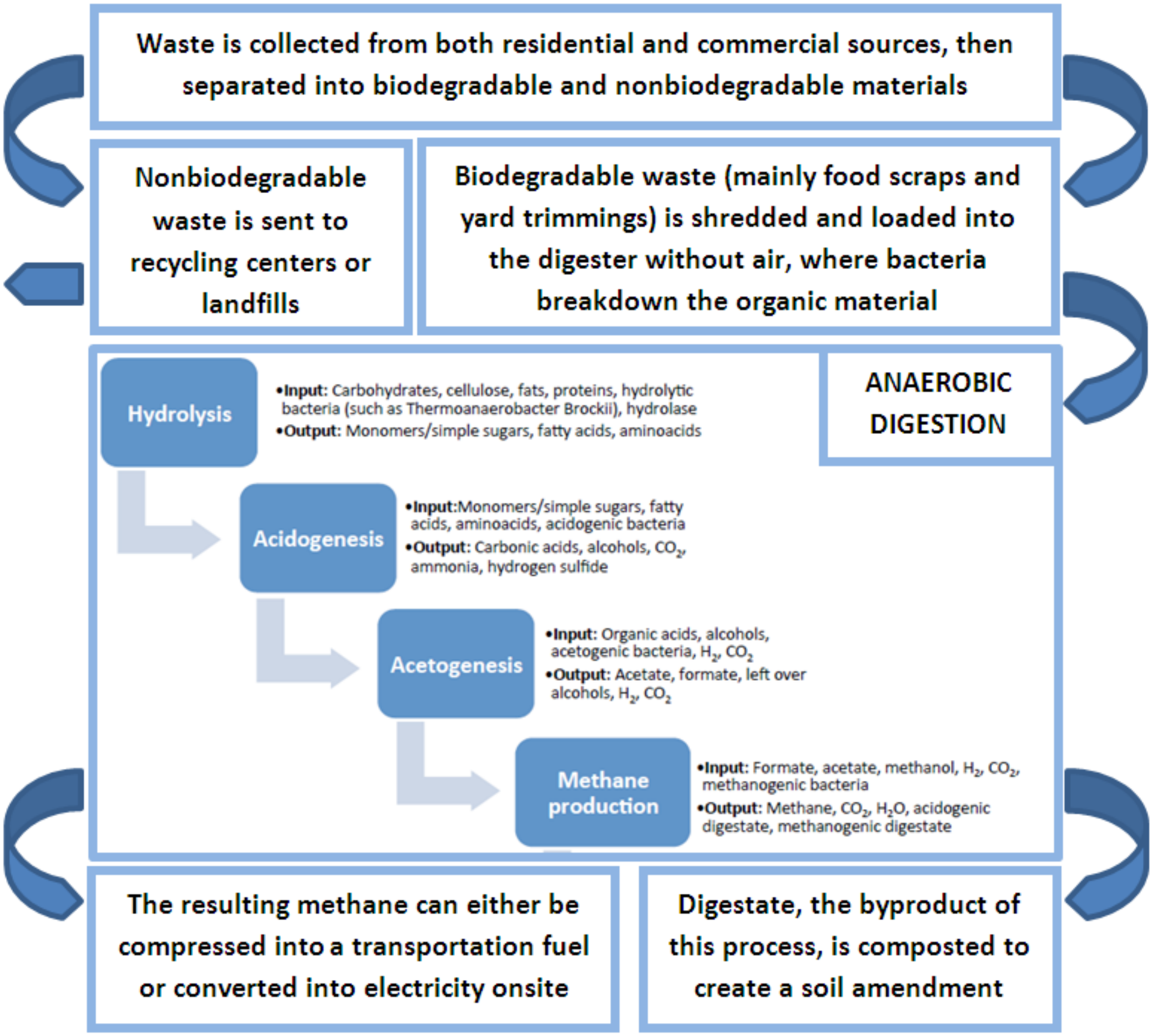

Figure 1. Process Diagram for Anaerobic Digestion of Organic Municipal Solid Waste.