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UNIVERSITY OF NEBRASKA LINCOLN; ENVIRONMENTAL STUDIES PROGRAM

How can an anaerobic digester benefit a community both environmentally and economically?

Senior Thesis

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Introduction

The purpose of this study was to analyze the current practices for utilizing biomass within a municipality and discuss what changes can be made to make the process more efficient, economical, and environmentally friendly. The study was conducted using the town of River Forest, Illinois as a representative town of America. The findings and structure of the study can be used as a template to improve other cities environmentally and economically.

The Village of River Forest has a population of approximately 11,100 residents. River Forest contracts Roy Strom Collection Company to manage refuse and recycling removal. According to river-forest.us; "All households receive standard service which provides for weekly refuse collection of up to two cans of refuse and two 18-gallon recycling bins (1)." This makes the datasets generated in the study much more accurate by individual households because virtually all residents of the town participate in the waste removal program. There are very few businesses in River forest so they do not play a large role in its overall waste removal numbers.

The current waste management procedures of River Forest will be discussed and compared with different options for heightening the efficiency of the villages' procedures in the future. The economic plausibility will be analyzed next to the intrinsic value and added natural capital of the changes. The changes include: Implementation of a local anaerobic digester capable of processing all of the community's organic wastes and converting the generated biogas into clean natural gas; the conversion of gasoline and diesel powered community service vehicles (police, fire, and collection vehicles) to natural gas powered; diversion of sewage to local digester site to use sewage as an organic source for more natural gas generation; and sale of organic byproduct as fertilizer and excess natural gas.

Purpose

This study has the possibility of benefitting anyone who pays for public or private waste removal. It can be used as a template to implement changes in other towns and cities. The residents of these towns could potentially pay less for the removal of their wastes while improving the air quality and natural capital of the area. The study (if suggestions are implemented), will also lessen the community's dependence on foreign oil by localizing the fuel production for the municipalities vehicles. In doing this, the city taxes could be reduced because natural gas is a much cheaper and efficient fuel than crude oil which would bring down the cost it takes to operate the required services of River Forest such as: Fire, Police, and other municipal vehicles.

If the implementation of the study is successful the idea can be replicated and modified to fit different villages, towns, or cities. The main conflict areas are the upfront costs of the project and potential cost of infrastructure changes for sewage and/or natural gas fuel use.

In conclusion this thesis will cover:

- What is anaerobic digestion?
- Examples of places digesters are used effectively to benefit the people and environment
- How will anaerobic digestion be used to help the Village of River Forest?
- Current practices of River Forest and the associated costs
- Natural Gas fueled vehicles
- Estimated cost of conversion to the suggested new plan
- Overall Costs and benefit analysis

Methods

To complete this study background research on anaerobic digestion and anaerobic digesters was conducted for one month. Interviews with related business setup and conducted over the course of one month. Businesses interviewed during this time are as follows: Harvest power, Roy Strom, Village of River Forest Public Works Department, and various natural gas companies. Upon completion of these interviews, collected information was organized and recorded with the background information. Necessary follow up interviews and research was conducted for one month. At this point the thesis paper was compiled and submitted for editing (one month). The entire process took approximately 4 months of periodic work.

Discussion

What is anaerobic digestion?

Biogas has been known to exist for many centuries but only in the last one have people begun to realize its true value. In the late eighteen hundreds England developed technology to help protect their septic systems (and the people who lived above) from the dangerous gases emitted by the waste that it carried. A lamp called the "sewer gas destructor lamp" was devised to burn off the harmful gases that would collect in high spots of the septic system and burn off some of the smell (1) (5). As the sewer systems developed and became more advanced most of these lamps fell into disuse (1) (5). What this discovery tells us however is that it is possible to create electricity from crude biogas.

Why is biogas valuable?

Biogas is a crude form of natural gas. Two primary gases make up biogas, 50 to 65 percent is made up of Methane (CH_4) and 35 to 40 percent is made up of Carbon Dioxide (CO_2). Four ingredients are needed to produce biogas, the organic matter, bacteria to begin the process of anaerobic digestion, the proper anaerobic conditions, and proper temperature (4) (2). The valuable component in the end product is methane gas.

Anaerobic digesters are in use all over the world. Many farms in India however use digesters to cook their food (7). They place the manure from their poultry and cattle into digesters. Digesters can be made from a multitude of sizes, shapes, and materials. Often they are a simple containment structure where waste is placed at the bottom, allowing the gases released during the process of anaerobic digestion to collect at the top (7). As gas collects at the top a pipe carries the gas into a stove or gas-light inside a nearby structure. These are very cheap to make and reasonably maintenance free. According to Kishore (7), in 2012 there will be approximately 200,000 terapascals of solid waste generated from cattle, poultry, and municipal waste used for energy in India. When the energy potential of these wastes is harnessed using current operational facilities; India has the ability to generate approximately 3,500 megawatts of energy (7). This is a tiny number next to India's overall consumption of electricity which according to the CIA World Fact Book stands at close to 600 million mega watts (9). But the fuel for that 3,500megawatts of energy is essentially free because currently it goes predominantly unused. After the organics have cycled through a digester much of the byproduct can be used for high quality fertilizer in farm fields due to its high concentration of nutrients. This number can also be greatly increased with the installation of more digester facilities.

Why are digesters not used more widely across the globe?

The bottom line is that anaerobic digesters become expensive when the gas has to be purified. India is able to implement so many digester facilities into use because the government will subsidize close to 50 percent of the overall project cost (7). As a result this subsidy has led to a wide development of digester facilities across India. What makes the purification process expensive is that biogas as stated previously is "low grade natural gas". This means that if it is not purified before it is run through the equipment it will wear down the materials reasonably quickly due to the hydrogen sulfide that is mixed in with the sequestered natural gas. To remove this, methane must be purified through a reasonably expensive water scrubbing (see *Figure 6*), distillation, or membrane filter process before it can be used to generate electricity (26). Membranes are a more cost effective method of purifying the methane but are difficult to use on large scale installations (8). Using an Iron sponge to purify biogas is a more cost effective alternative to the former purification techniques. An Iron Sponge works by essentially forcing the biogas downward through a cylinder packed with iron sponge (27). The Iron oxide reacts with the hydrogen sulfide to produce iron sulfide and water. The water is drained as it reaches the bottom and the gas, now purified, continues through the system.

Figure 6: (26) A picture of a water scrubbing unit that is part of a biogas plant in Trollhättan, Sweden

Most of the commercial business and residential interest in the technology is lost when the expense of operating and maintaining such technology is calculated. If local electricity is cheap enough, comparing a biogas powered generator next to the conventional generator will prove economically inadequate. However, with the help of government subsidies in the United States similar to those given in India, the potential for a more wide use of digesters is possible. What it takes is forward thinking individuals in both the public and private sector to realize that the long term environmental benefits outweigh the upfront expense.

CNG and LNG generation from biomethane

Compressed Natural Gas or CNG is a vehicle fuel source currently growing in popularity. The majority of cars and light-trucks can be converted to Compressed Natural Gas. The natural gas is compressed into 1% of its standard volume and pumped into tanks (19). Vehicles can be retrofitted to hold similar tanks that allow the vehicle to burn natural gas instead of gasoline or diesel. Natural gas burns far cleaner than gasoline or diesel, and costs far less so it has no real

negatives, outside of some safety elements. The approximate cost for converting a vehicle from gasoline to CNG runs between 6,000 and 12,000 dollars due to the high cost of tanks or fuel cells and stringent regulation of retrofitting projects by the Environmental Protection Agency and other government agencies (0.5, 0.6). To do it yourself the cost is significantly less, running anywhere from a thousand to five thousand dollars for a conversion kit, but one must keep in mind the highly technical nature of some of the work and the safety implications if something is done wrong (21, 22, 23). This is part of the reason for the strict standards by the EPA and why they require people who do it themselves to have their work checked by a professional to certify the converted vehicle- "road worthy". Under Title 42 of the United States Code, Chapter 85- Subchapter II- Part C- § 7587) The Clean Air Act threatens hefty fines for everyday that a person is caught in violation of their rule on modifying fuel systems which would most likely be what someone who converted their vehicle themselves would fall into (21, 27). Under this same subchapter the law outlines the standards that must be met before the vehicle is considered in compliance with their regulations (27).

For large trucks such as municipal trucks, sanitation trucks, and other long-haul trucks, Liquid Natural Gas can be used as a fuel source. Liquefied Natural Gas is a recently developed product that can produce as much power as diesel fuel at approximately half the cost to the consumer at the pump (20). The most logical thing to do may be to begin buying new or used LNG trucks thereby saving on the cost of retrofits and buying a more reliable vehicle for the future.

The concern with natural gas is that the high pressure tanks pose a potential safety hazard in auto accidents because people are worried that they would explode. This is a logical concern to have and the NGV manufacturers have solved this problem. The vehicles are created with a

very thick tank usually have multiple hulls or shells. These tanks are much thicker than is necessary to simply contain the pressurized gas. They are built in this manner to contain the pressurized gas in the event the tank is physically impacted. If the tank was to puncture, it has been designed to release gas at a controlled rate. There are pressure release valves that release gas to prevent pressurized explosions. Even if the gas was to catch flame the pressure release valves will control the release of the gas like a Bunsen burner. It will simply burn till the gas in the tank has burned out. The system controls the release of the gas so that it is actually safer than a gas tank because the gas does not pool around the vehicle like a liquid would, instead it dissipates into the air and becomes harmless.

Ignoring all of the environmental benefits of switching to biogas generated power; the generation of electricity from biogas is far more cost effective than purifying the biogas into natural gas. It is much easier to generate electricity due to the cost of membrane filters, water scrubbing equipment and other purification technology, next to building an useable infrastructure for natural gas powered vehicles and replacing or retrofitting old vehicles with CNG or LNG drive capabilities. However, once infrastructure, replacement and retrofitting of vehicles are in place and costs have been internalized CNG and LNG become a very real and environmentally sound possibility.

Electrical Generation from biomethane

Currently Roy Strom collects refuse and recycling from approximately 2900-3000 households in River Forest. This is about 75% of the total households in the village. The company sends between two and three trucks to do pick up each week. It takes Roy Strom three days to complete the weekly pickup using special dual collection trucks that pickup recycling

and refuse at the same time saving money on gas. However, even with their efficient system for pickup they use between 20 and 25 gallons of fuel per truck per day. This amounts to approximately 187.5 gallons of fuel per week if the average 2.5 trucks are used. Two trucks use 150 gallons and when three trucks are in use on high volume days they consume 225 gallons. Part of the reason for the high fuel use is the distance the trucks must drive to dump their load. Illinois legislation, restricts any landfill from being built or expanded within counties with populations over two million people. The governor signed this bill with pressure from people with the “not in my back yard” philosophy. This forced communities outside the Chicagoland area to shoulder the burden of Cook County’s wastes. Presently, Roy Strom must drive their trucks to Greenwood Transfer station in Maywood, Illinois. The municipal solid waste is sorted onto separate trucks that drive the garbage 90 miles to be disposed of in a sanitary landfill in Rockford, Illinois. Yard waste must also be sorted out (woody biomass, grass clippings, leaves, ect.) because yard waste is not allowed in landfills because of how quickly such waste fills up a landfill. Instead, yard waste is transported to separate composting areas approximately 50 miles away.

Figure 5 shows that Roy Strom picks up an average of 206 tons of refuse, 114 tons of recyclables, and 24 tons of yard waste per month (yard waste varies greatly by season). If the tonnage River Forest’s Public Works Department is added to the yard waste total it approaches 50 tons per month. An anaerobic digester appropriate for this volume of waste requires approximately 10,000 tons per year. Depending on the complexity of the carbohydrates within the organic matter being used to fuel the digester, greater volumes of gas can be produced. Organics with more complex carbohydrates lead to larger quantities of gas once they are digested. From start to finish, the residence time for this digester is 10 to 16 days (Katie Oliver,

CleanWorld). Residence time is the length of time it takes for the organic matter put in at the beginning of the digestion cycle to make it to the end. At this point the bacteria in the digester have broken down and released the predominant portion of the accessible energy in the organic inputs and this left over waste is removed to be thrown out, sold, or given to the public as a fertilizer.

Figure 5:

Roy Strom

Month	Refuse	Recycling	Yardwaste	Special Notes
2011 July	213.00	103.00	29.27	
2011 August	247.05	116.64	35.13	
2011 September	228.05	105.74	25.28	
2011 October	202.54	108.54	23.22	
2011 November	241.96	171.28	14.18	
2011 December	229.75	118.65		misc. leaves
2012 January	215.55	116.98	19.5	Christmas Trees
2012 February	174.33	95.10		N/A
2012 March	206.58	102.71	11.36	Storm Debris
2012 April	118.11	111.20	38.9	
2012 June	190.57	106.14	27.91	
Average	206.14	114.18	24.97	
2012 est. July	237.06	131.31	28.72	Estimate Average of 11 months + 15%

This digester would produce 150,000 diesel gallon equivalents in biogas. This would easily fuel all of the waste management trucks and many of the city vehicles. Since there are public natural gas fueling stations in the neighboring town of Oak Park the natural gas captured during the process could also be sold to help pay off the facility. If a larger digester is used, it is possible to use the byproduct of wastewater treatment called sewage sludge as fuel for the digester and generate electricity from the high organic content in sludge.

Background

Humans and animals produce large quantities of organic matter in the form of feces every day. This organic matter emits large quantities of biogas (or crude natural gas). Enough in fact to power much of our electricity needs. According to the Environmental Protection Agency, methane is twenty times more effective at trapping infrared radiation than carbon dioxide (3). This means that allowing the vast amounts of human and animal waste to breakdown without capturing will introduce increased amounts of methane into the atmosphere as our population grows. Burning Methane however decreases the effect by twenty because the byproduct of burning methane is carbon dioxide (which is less harmful). This, obviously, is not the only benefit. Many people are turned off by the idea of using municipal wastes for fertilizer because it has the stigma for being dangerous and smelly. After the human or animal waste goes through the process of anaerobic digestion, the exact opposite is found. So, public education on the benefits of such processes are necessary to make such a process possible.

Anaerobic digestion is a reasonably complicated process. There are four main stages; Hydrolysis, Acidogenesis, Acetogenesis, and Methanogenesis (15). Acetogens break down organic material to form acetic acid (15). Methanogens break down organic material to form methane (15).

Figure 1:

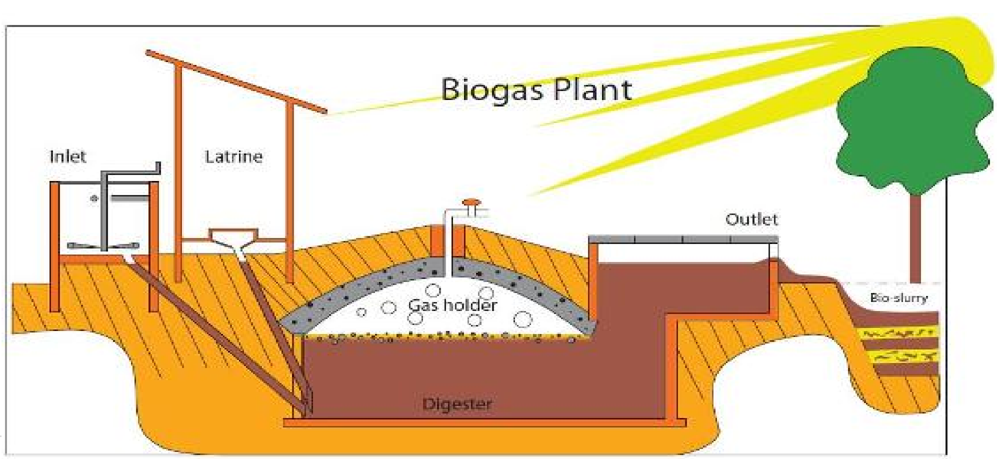


Figure 1 shows a small residential digester is has a very simple structure. Biomass is input (in this case through an inlet and latrine) into the digester. These are called, “single stage” digesters because all biological reactions occur within a single tank. These are far cheaper because of the lack of complexity and they have a much shorter residence time from when the biomass enters the tank to when it exits, at around 14 days. A problem with single stage digesters is that they can have an unstable pH, with sensitive bacteria. Bacteria like most organisms are capable of living in specified environmental niches. If the pH in the tank fluctuates too much one way or another it will slow bacterial activity or kill them off all together. As a result a poorer product is created.

Figure 2: (14)

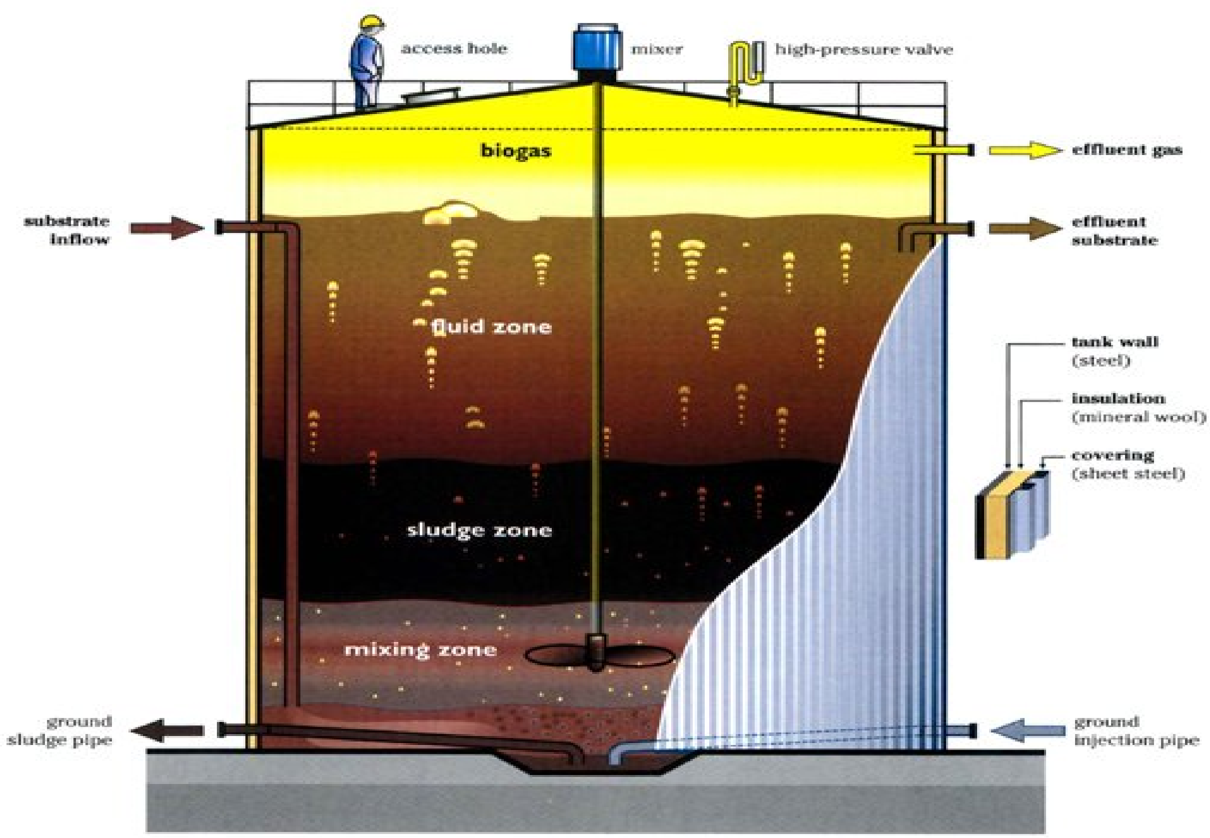
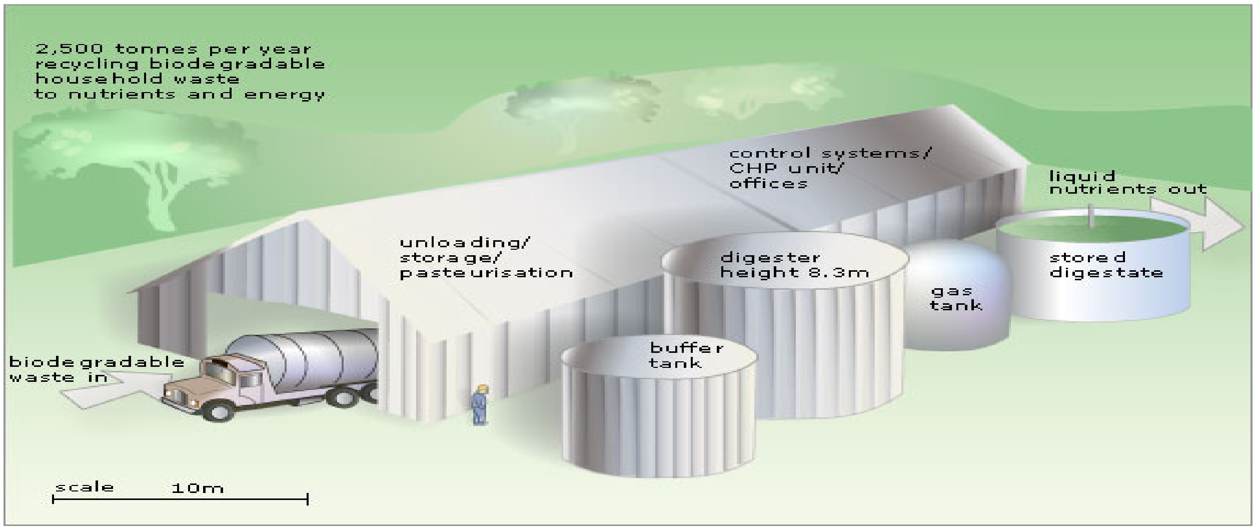


Figure 3: (13)

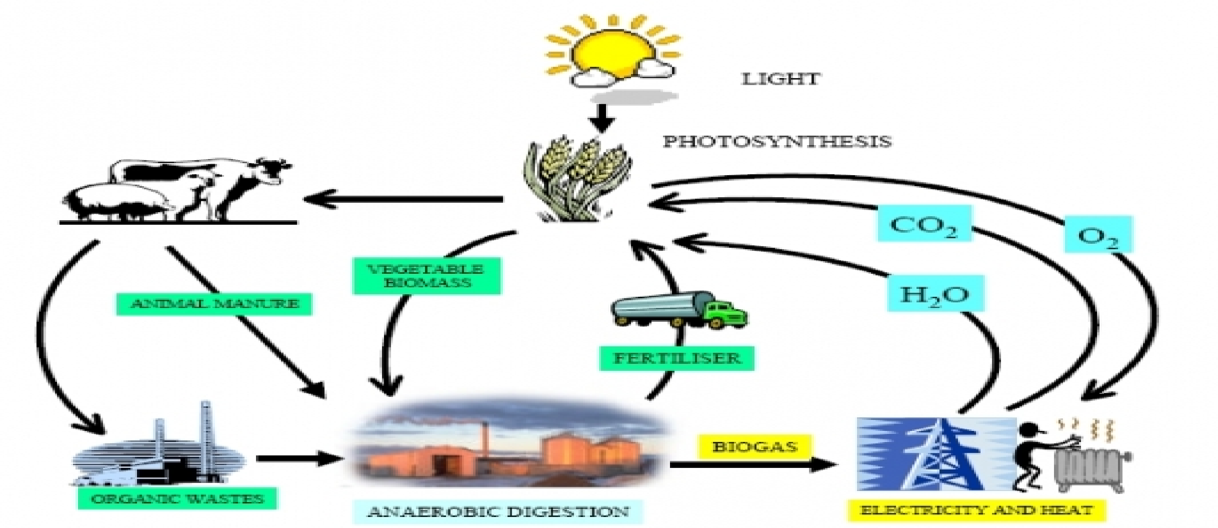


For higher quality gas and byproduct, multistage digesters should be used. *Figure 3* depicts the basic construction of a multistage digester for solid waste. Multiple holding vessels are used to bring bacteria under as much control as possible instead of just one tank. This stabilizes the pH and bacterial activity, thereby producing a more consistent and pure product. Because of the size of the facility and the multiple holding vessels the residence time of the biomass is much higher anywhere between 15 and 40 days. The greater complexity of this type of digester breeds much higher cost for construction and operations and maintenance (10). This is why single stage digesters are a more popular method. *Figure 2* depicts a more detailed diagram of the mechanics of each vessel.

In the process only the natural gases are sequestered from the biomass, the leftover solids exit the digester at the completion of a cycle. Temperature and time kill harmful bacteria during the anaerobic process. The resulting solids are safe and nutrient rich, with a distinct but not obscene odor. This of course is dependent on the residence time within the digester, the

temperature, and the quality of the biomass used (2). The owner now has the capability to use or sell electricity and fertilizer. *Figure 4* shows that with the responsible use of digesters, a community can create a very efficient and lucrative recycling process.

Figure 4: (12)



Once the people are made aware of the benefits and the potential of anaerobic digestion facilities, they have the ability to convince the government to implement tax breaks, and incentives that will make the move more economical. Greater funding in this sector will make the process more efficient and potentially cheaper for the purchaser. If incentives are created by the government, the cost benefit analysis for the implementation of such technology is now much more lucrative for a power company because not only are they able to sell power but they can also sell manure. The waste water treatment plants in Lincoln have already recognized the benefits of anaerobic digestion; their digesters produce over 900 kilowatts of power, therein decreasing the need for fossil fuels (11). The United States could export more of our coal instead of burning it, thus bringing in more Gross Domestic Product. The biogas/natural gas industry will produce jobs and call for resources. The benefits are clear, if we are able to show power

companies the long term value of such practices we would be a cleaner, more sustainable society.

Implementing a digester into the future plans for the Village of River Forest and/or surrounding towns, cities, and villages would create the essence of what a community should strive to be; forward thinking, environmentally conscious, and responsible. The Village of River Forest would pave the way for other towns to follow in its footsteps. Implementing a digester would also allow the village to discuss retrofitting or replacing their vehicles with natural gas drive engines that can be powered by the purified biomethane generated in the digestion process, thus reducing their footprint even more.

According to CleanWorld 10,000 ton per year facility would produce 150,000 DGE, 1.35 million gallons of liquid fertilizer and 1,100 tons of solid compost material at 4.8 million dollars. If this cost was spread among two or more towns it would be significantly cheaper for each town and allow them to upgrade to a larger facility due to the larger organic inputs. Karen Rozmus Environmental Manager of the Village of Oak Park found that between January 2011 and November 2011 Oak Park collected 9,100 tons of refuse, 1,100 tons of yard waste and approximately 2,700 tons of leaves. This was during a severe drought; Oak Park typically sees around 3,400 tons of leaves during this period. After toxic items are separated from the refuse the tonnage amounts to approximately 6000 tons, when the yard waste and leaves are added this number approaches 10,000 tons in 11 months. This means Oak Park alone has the ability to run their own digestion facility.

If Oak Park and River Forest shared the cost of a larger facility requiring 20,000 tons per year, their capital investment would only increase to 6.1 million. Such a facility has the potential to

produce 5.6 GWh of electricity, 2.75 million gallons of liquid fertilizer, and 2,875 tons of solid compost material (Katie Oliver, CleanWorld). According to clean world both of these digesters have a potential payoff period of 5 to 5.2 years.

The 20,000 tons per year, 600 thousand gallon facility costs are below in *Figure 5*.

Figure 5: Provided by CleanWorld

Annual Revenue	$1,457,000
Operating Expenses	**(289,000)**
EBITDA	**$1,168,000**
Depreciation & Amortization	(273,000)
Pre-tax Earnings	**$ 895,000**
System Capital Cost	$6,100,000
IRR	**20.2%**

These numbers assume that there is an inflation rate of 3 percent, an electricity price of 9.5 cents per kWh, tipping fees at 30 dollars per ton, and a liquid fertilizer revenue of 10 cents per gallon.

According to the U.S. Energy Information Administration the average home uses 11,040 kWh of electricity. 5.6GWh is the equivalent of 5,600,000 kWh. In theory this means that 5.6 GWh is enough to meet the needs of 507 homes. Although this does not seem like much, 507 homes is 25 percent of River Forest which has about 4,000 homes. So 25 percent of the town's energy needs are met using a renewable energy source.

As was discussed previously, anaerobic digestion is a natural process that occurs in our Earth's natural cycles. If yard waste, animal feces or any other organic matter were left where they lay they would begin to breakdown within a matter of days or even hours. Bacteria, microbes, and insects all play roles in this breakdown, reducing the original waste into basic particles and gases in the final stages of breakdown. The gases released; Methane and Carbon Dioxide are potent green house gases which aide in global warming and climate change (25). If

this process was contained within an anaerobic digestion facility, the gases could be captured and burned as a source of power. Burning the methane changes the chemical composition of the gas into carbon dioxide a gas which is upwards of twenty times less potent of a greenhouse gas than methane. In its chemical form methane is made up of 4 hydrogen atoms and 1 carbon atom, when combusted 1 carbon dioxide molecule is released and 4 water molecules rendering natural gas as the second cleanest fuel source for green house emissions just behind hydrogen fuel (22). Methane has high potential energy so allowing it to be released into the atmosphere is potentially harmful for the environment as well as a wasted source of energy.

In building a digester River Forest would become a much greener town, it would clean up its air quality, recycle around 60 to 70 percent of its organic wastes, and use the energy to power its vehicles and potentially its buildings. This is a great selling point for future residents and adds one more reason to the many reasons why River Forest is the place to live. So this has the potential to drive up property cost, and lower property taxes because the village would potentially be less expensive to run. There is also a "feel good" component in that every resident is contributing to being responsible stewards of their environment without expending any more effort than they would have with the original system for waste removal.

According to the 2010 report by the United States Energy Information Agency, nuclear energy makes up 50.1 percent of Illinois' electric industry, whereas, coal energy makes up 46.1 percent , and natural gas makes up only 2.6 percent of the industry (24). Nuclear energy is far more expensive than coal and natural gas because of security, operations and maintenance, and spent fuel disposal costs. Coal is much cheaper running about 170 cents per million Btu in 2010 but its emissions are detrimental to the air quality as well as the environmental quality of the land it came from (24). Natural gas is more expensive running around 529 cents per million Btu but it

burns cleanly expelling predominantly carbon dioxide when it is burned as appose to the sulfur and other harmful particulates emitted by coal burning plants (24). Keep in mind that the price mentioned for natural gas is the price for natural gas taken from underground and not from a digester. There are significant economic and environmental costs in mining for natural gas that do not overlap when comparing the biogas/methane generated by a digester. Biogas would undercut the power company's overhead costs rendering the electricity generated from a digester cheaper for the village and its residence if it were put into use locally.

In conclusion, a digestion facility would benefit the community of River Forest in the following ways; firstly, it would reduce the environmental and intrinsic costs of transporting organic waste to the current repository 50 to 90 miles away. Secondly, the biogas captured from the digestion process could be used to generate power for the community and other areas, natural gas for fuel cell vehicles, or natural gas for sale. As was stated above this form of power generation is cleaner than coal and natural gas (when you consider harmful effects of fracking) and safer and cheaper than nuclear. Thirdly, the leftover organic products of the digestion process can be sold or given away to use as fertilizers. The overall best case scenario for an overhaul would incorporate, purchase of land, installation of the facility, potential sewage infrastructure changes, facility operation and maintenance costs, potential conversion of vehicles to fuel cell technology and potential natural gas pumping stations for vehicles.

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