Worming the Way to a Greener Future:

Vermicomposting for Municipal Organic Waste Disposal

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Background

In the fall of 2012, I had to begin working on my senior thesis. I was set to graduate from Hendrix College in May of 2013. The thesis could cover any topic related to my major, Environmental Studies. That’s quite a broad range of options, so I started narrowing down my ideas. In the summer of 2012, I’d worked at the Kerr Center and done a lot of interesting work and I thought that might be a good place to start looking for ideas because I knew I wanted to write about something having to do with sustainability and agriculture. The Intern Program Coordinator had afforded me the ability to start a vermicompost system at the Kerr Center; in doing so I did a lot of research about vermicomposting and had written a short report in the end. It seemed like a perfect starting place. I had to try to make a point, though; I couldn’t just write about vermicomposting objectively. I chose to write about how a vermicomposting system could best be set up for a whole town. For argument’s sake, I focused my “test site” on Conway, Arkansas (where Hendrix is located), and looked at all of the contingencies of large-scale vermicomposting. In the end, I found that we are still far off from that reality, but in writing the thesis I learned more about vermicompost, worms, and community sustainability efforts. You can read this work all the way through, or you can use it more as a primer on vermicomposting by focusing on Sections 4 and 5. They discuss the science of vermicomposting and can be applied to small- or large-scale operations on your own farm. I hope you enjoy it and find it helpful!

-Katie

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Abstract

The United States produces 250 million pounds of municipal solid waste per year in addition to millions of pounds solid waste excrement termed sewage sludge. Between 13% and 29% of that municipal solid waste is organic material that can be “recycled” back into the Earth. Vermicomposting is an efficient method of turning organic waste into valuable soil full of nutrients that are bioavailable. Epigeic Earthworms work through the organic waste, eating up to half their body weight per day. Once the worm excretes the waste, it has been turned into worm castings that resemble soil. Nutrients are converted to bioavailable forms while in the digestive tract of the worm, making them readily accessible by plants. This paper looks at the process of vermicomposting and discusses the infrastructure changes necessary in a United States city in the context of a case study of Conway, Arkansas. It also explores the pros and cons of vermicomposting on a large scale. Recommendations are made for future changes to the waste stream in both Conway and other cities in the United States.

Introduction

The United States produces approximately 249.9 million tons of solid waste each year (as of 2010) at a rate of 4.43 pounds per person per day (EPA 2012c). Figure 1 below shows the alarming growth of waste generation in the United States since 1960. These numbers reflect the amount of municipal solid waste thrown out every year and do not even include the sewage wastes flushed down the toilet. Of that 249.9 million tons of household and industrial waste, approximately 85 million tons were recycled or composted-- a 34.1% recycling rate (EPA 2012c). The other 165 million tons went into landfills. This volume of trash is cause for concern, both for the environment and the economy. Environmentally, landfills pose risks to those living around the area, including humans, animals, and plants. Gases escape the landfill and leachates run out in groundwater and through the soil, carrying dangerous chemicals such as PFCs and PBDEs (perfluorocarbons and polybrominated diphenyl ethers) from plastics, which can cause irreparable damage to the nervous and reproductive systems of animals and humans even in low concentrations (Li 2012). The government usually coordinates the cleanup needed to rectify these dangerous situations and pays for it with tax money. That money could

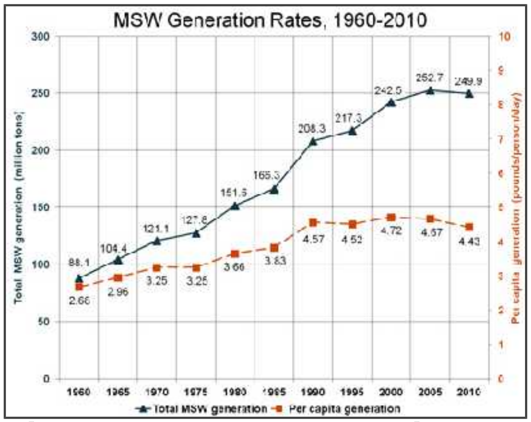

Figure 1: Waste Generation Rates in the United States, 1960-2010. Courtesy US Environmental Protection Agency.

be better spent had the hazardous circumstances been avoided altogether.

Municipal Solid Waste is not the only waste stream that the city must manage. Sewage sludge makes up a huge portion of the waste a city must regulate and discard. Sewage sludge is the human excrement flushed down the toilet, as well as foods put down the garbage disposal. Each city devises its own method of decontamination and disposal; that generally means that the city finds the least expensive method, but does not guarantee that the method is the safest for humans or the environment. The Environmental Protection Agency (EPA) lists the most common final disposal means in Rules and Regulations found in the February 19, 1993 Federal Register (EPA 1993)**.** The methods include land application, marketing of sludge for home gardens, disposal into municipal landfills, collection in a monofill (a landfill with only sludge), or incineration. Of course, prior to these disposal actions, the sludge must be brought to regulation in terms of sanitation and processing; thereafter it is termed “biosolids.” Depositing biosolids into a landfill or monofill or incinerating it are the least environmentally-friendly ways to dispose of waste. Applying the biosolids to public lands or to home gardens are preferable methods because nutrients are returned to the Earth. The EPA acknowledged this use in their document stating: “The organic and nutrient content of sewage sludge (biosolids) makes it a valuable resource to use both in improving marginal lands and as a supplement to fertilizers and soil conditioners” (EPA 1993). They later affirmed the usefulness of applying biosolids to stabilize and re-vegetate harvested forestlands, mining operations, and dredging operations. As part of the stabilization process, the agency found that microbial populations returned to their natural range in as few as two to three years after sludge application to those lands, whereas the process would naturally take ten to fifteen years without biosolids application (EPA 1993).

While the reclamation of land by natural processes is slow, it is sure. The Earth has functioned for millions of years by cycling nutrients. Figure 2 on page 6 outlines some of the many ways nutrients are “recycled” in nature. Trees take nutrients from the soil and energy from the sun to produce leaves, which feed the tree; then the leaves fall and the nutrients are reincorporated into the soil. Animals die and their bodies are eaten by others or are left to decompose back into the soil with the help of time and natural “recyclers” like mushrooms and other fungi. The key six elements present in all life forms- hydrogen, oxygen, carbon, nitrogen, phosphorous, and sulfur- must be recycled in these pathways for life to continue. Hydrogen, oxygen, carbon, and nitrogen make up approximately 99% of the mass of most cells. Different combinations and conformations of those elements allow organisms to accomplish complex tasks such as photosynthesis, respiration, and metabolism. The Earth has maintained life for millions of years via the cycling and reuse of these elements. Early humans buried food wastes or gave them to animals and human excrement was left in the woods where it could decompose and sustain plant life. Those methods perpetuated the closed-loop cycling of nutrients, where they never went to waste and were always reused. However, in recent times, humans have disrupted the cycle by isolating organic waste into landfills. Rather than return nutrients from food to the Earth, discarding food into a landfill means it cannot be broken down and reincorporated into the plant ecosystem. This open-loop cycle that runs from producer to consumer to landfill is fast in motion in America, where 165 million tons of waste is deposited into landfills yearly (EPA 2012c).

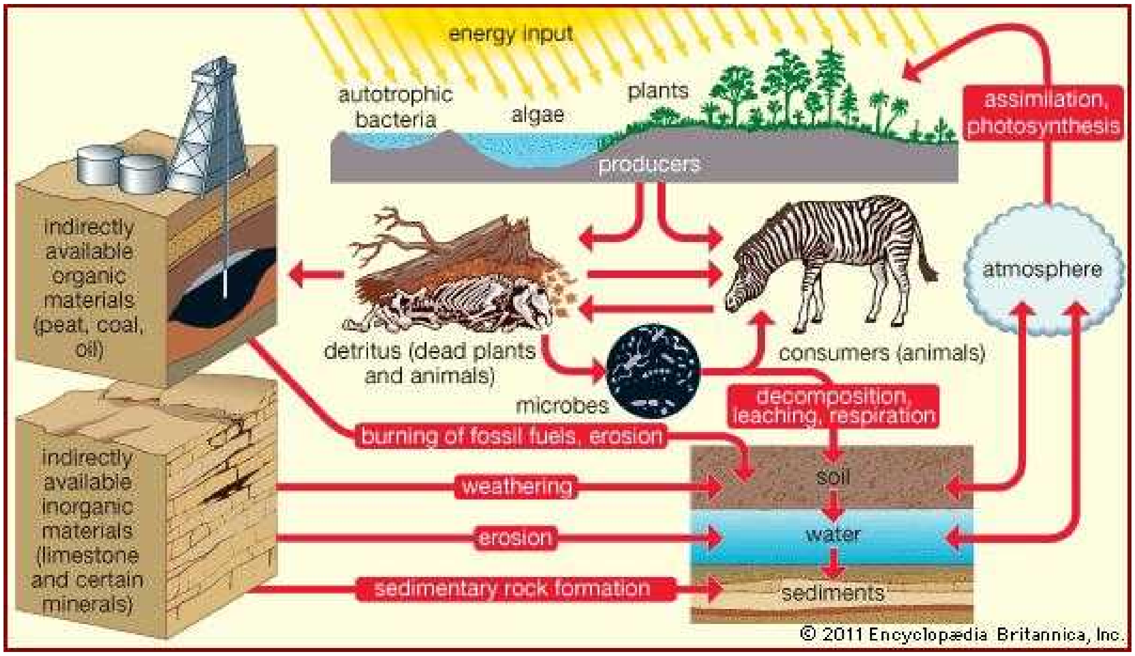

Figure 2: Natural nutrient cycling. Photo courtesy Encyclopedia Britannica 2011.

This disruptive open-loop trash cycle causes a breakdown in the system of food production and causes topsoil loss. Topsoil is the most nutrient-rich region of the soil; without it, crops cannot grow as healthily or as quickly. When organic material is not added back to soil that is supporting plants, there is no substance to form the topsoil layer. The United States is losing topsoil at a rate ten times faster than it can be replenished (Lang 2006). That is a serious problem for both farmers and consumers alike. Over a long period of time, the loss of topsoil will cause food prices to skyrocket because farmers must buy synthetic fertilizers and employ more land to grow enough food on nutrient depleted land. To fix these problems of landfill overuse, breakdown of the nutrient recycling system, and topsoil loss, a new method of waste disposal must be imagined and implemented. One option that mirrors natural processes and returns organic matter back to the Earth is called vermicomposting.

Vermicomposting is the process of breaking down organic wastes, both food and excrement, with Earthworms. Vermicastings, or the excrement of the Earthworms, have a high nutrient value and a relatively high amount of beneficial microorganisms. When added to soil, vermicastings increase the moisture retention rate and the amount of plant-available nutrients as well as buffer the soil to reduce the harmful effects of excessively acidic or basic soils (Applehof 1982). Fruits and vegetables that are raw or have been cooked without excessive grease or oil can be vermicomposted. The worms can also easily process coffee grounds, tea bags, eggshells, and yard wastes (Applehof 1982). Sewage sludge can be vermicomposted, though it is a bit trickier. The breakdown process (of food waste or sewage sludge) takes up to six months, depending on the amount of waste and the density. The wait is worth it though: the end product is rich, black vermicastings that have no pathogens and can be applied liberally to agricultural fields, gardens, and landscaping (Applehof 1982). If a city implemented vermicomposting, the vermicastings could then be sold by the city to private landscapers, farmers, and gardeners and used in city flowerbeds and parks. Commercial vermicastings sell for up to $330/cubic yard (Red Worm 2013). The sale would help offset the initial cost of implementing the vermicomposting program as well as beautify city landscaping without having to pay for economically and environmentally expensive fertilizers.

Vermicomposting can be executed in several ways. No cities in the

United States have a vermicompost program, though some private companies vermicompost food or fecal wastes (Edwards 2009). Worldwide, vermicomposting is utilized in many small cities and villages, such as Mandhana and Metoda in India, to solve the problem of waste disposal and to fortify agricultural soil (Daniel 2005). Though the scale of most of these programs is too small to be mimicked in the United States, some key points can be used and modified to succeed in the U.S. Small villages often use vacant lots for vermicomposting by digging pits in which to place the organic wastes and worms. Most American citizens would not want to live near vermicomposting pits but fortunately almost every city has some amount of land that is already used for sewage treatment or for yard waste composting, often outside the city limits. Certain cities might be able to buy open lots to vermicompost yard and food wastes; the odors would be minimal and the lot could be located outside the city limits as well (Trautmann 1996). Sewage sludge can be mixed with the food and yard wastes and vermicomposted; however, it is a large undertaking and some cities might choose to start small with only food and yard wastes. In the end, the product would be a nutrient-rich and stable fertilizer that holds moisture better than typical soils (Lowenfels and Lewis 2010). For some cities, it would save about 27% of space in a landfill (13.9% food scraps and 13.4% yard wastes), while in others that now landfill sewage sludge, it could save even more space while returning valuable nutrients to the Earth (EPA 2012c).

To examine the benefits and difficulties associated with launching a vermicompost system in a U. S. city, the city of Conway, Arkansas will be used as a model. Conway has a population of 58,908 spread over 60 square miles (City of Conway 2012). The household and commercial waste is disposed of in a sanitary landfill just outside of the city. A conventional activated sludge treatment plant anaerobically digests the sewage sludge; then, the stabilized waste is applied to land around the city. The current system is not unusual for similarly sized cities in the United States so Conway ought to serve as a good model.

This paper will discuss the amount of waste generated in the United States and how that relates to environmental and human health. Then it will discuss the process of vermicomposting and how it can rectify many problems associated with the disrupted nutrient cycle in the US. To implement a program would require public participation and city funds, each requiring specialized programs to raise support. The city of Conway will serve as a model for vermicomposting implementation in other US cities.

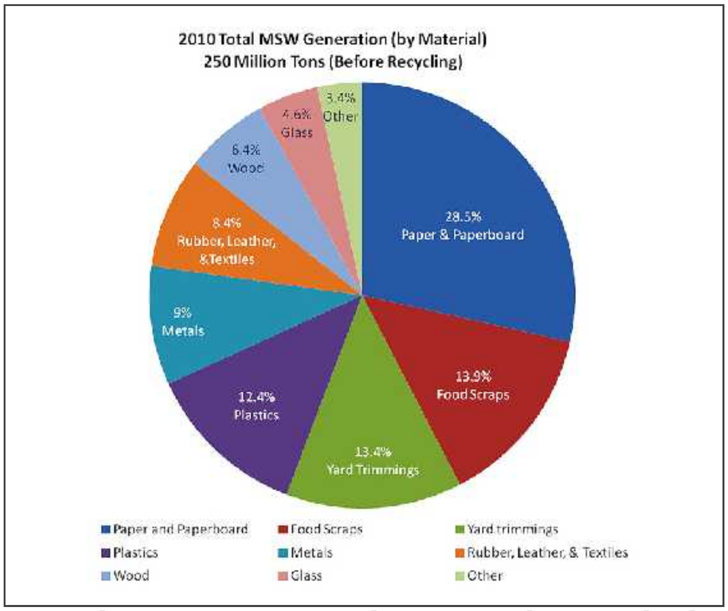

Figure 3: Types of Waste Disposed of in the United States. Courtesy US Environmental Protection Agency.

Problem of Waste in the United States

The United States produces

the most waste in the world per person. Over 1,675 pounds of waste per person per year is produced in the USA, which is 154 *more* pounds/person/year than the next-most “trashy” country, Australia (Nation Master 2002). Of that 1,675 pounds of waste per person per year, about 88% can be reused, recycled, or composted (see Figure 3). Instead, only about 34.1% of all waste produced in 2010 was recycled or composted (EPA 2012c). Almost all plastics, paper, metals, and glass can be recycled and reused multiple times. All yard trimmings and food scraps can be composted or vermicomposted so nutrients can be returned to the land instead of being locked up in a landfill. Unfortunately, the other 10-12% of municipal solid waste must be discarded without further reuse or recycling. Examples include some types of plastics, biohazardous waste from health clinics, aerosol cans, diapers, plastic-coated boxes, contaminated mixed media, and tires. Additionally, toxic waste such as motor oil, antifreeze, and other chemicals must be completely sealed and disposed of in a safe way (Baskind 2010). Though many types of products must be thrown away, overall most “trash” can be kept out of landfills and some can even be used to help the Earth.

In addition to the 88% of household and industrial waste that can be recycled or composted, almost everything flushed down the toilet can also be utilized to benefit the Earth. Many Americans consider sewage sludge to be a toxic and unusable garbage. On the contrary, that waste is valuable and full of nutrients from the foods humans digest. The United States produces approximately 117,000,000 pounds of dry solid waste each day (McDaniel 2013). As with food scraps and yard trimmings, this “waste” can be processed with composting and vermicomposting and added back to the soil for use in growing food and pasturing livestock, closing the nutrient cycle and allowing the Earth to make use of natural “recycling.”

The natural “recycling” not only returns nutrients to the soil but also organic matter, in the form of topsoil. Topsoil constitutes valuable area to grow crops in and it is one of the most nutrient-rich layers of soil because any dead organic matter that falls onto the soil is incorporated into the top-most layer through natural degradation or with the help of Earthworms and beneficial microorganisms. Nutrients include the major six elements needed for life (hydrogen, oxygen, carbon, nitrogen, phosphorous, and sulfur) as well as other key trace elements such as calcium, potassium, sodium, and iron. Discarding food into a landfill prevents it from being reincorporated into the Earth where it can be utilized for generations to come. Food thrown into a landfill cannot breakdown well because the lack of oxygen prevents most microbial activity. Any foodstuff that does biodegrade in a landfill is not very useful to humans not only because the nutrients are sequestered in the landfill but also because anaerobic bacterial breakdown of organic wastes produces methane and carbon dioxide emissions, which are both greenhouse gases (EPA 2012a). Replacing the nutrients and organic matter is crucial in this day and age because unsustainable farming practices paired with already-dwindling topsoil replacement are causing conditions allowing for widespread topsoil loss during natural events. It has been reported that a typical rainstorm can wash away one millimeter of topsoil, which is over 5.2 tons per acre (Lang 2006). The annual productivity losses caused by the lack of topsoil are estimated at $37.6 billion a year in the United States (Lang 2006).

Household garbage is almost always transferred to a Municipal Solid Waste Landfill (MSWLF), which is cleared to hold “non-hazardous sludge, industrial solid waste, and construction and demolition debris” that complies with federal regulations (EPA 2012b). The EPA has environmental regulations on those types of landfills that include where the landfill can be sited and which types of on-site environmental monitoring systems must be put into place. Monitoring systems look for safety breaches and leaks stemming from items such as paints, cleaners, oil, batteries, household appliances, and pesticides. The EPA also has regulations on how a landfill must be closed up to be considered “sanitary” once it is full. It is required to be covered with a relatively non-permeable plastic lining and eighteen inches of earthen material as well as six more inches of earthen material capable of supporting native plant growth. It must also be monitored for groundwater contamination and methane gas release for at least thirty years (EPA 2012b). All of these processes cost money in the short- and long-term. To produce the cap that covers the landfill, the Maryland Department of the Environment estimates a cost between $80,000 and $500,000 per acre, depending on the local availability of some resources such as clay and gravel. The monitoring systems run about $10,000 to $20,000 per acre (Maryland Department of the Environment). Clearly, closing a landfill is a major ordeal. The process of closing a landfill costs money that typically has been set aside from the monthly or yearly bills for using the landfill. In the end, those citizens using the landfill would save money, help the environment, and safeguard their health by reducing waste and sorting and diverting recyclable and compostable wastes so that the landfill could stay open longer to collect wastes that really must be thrown away.

Another important reason to look for new methods of waste disposal is the ecological impacts of landfills. MSWLFs are not reliably clean, even though they are monitored by very expensive systems- up to $20,000 an acre! (Maryland Department of the Environment). Regulated wastes can still have shocking impacts; for example, yard wastes might be coated in pesticides or herbicides and plastics have byproducts that do not biodegrade and can be harmful to human and animal health (Li 2012). The main problem, though, is inappropriate discarding of chemicals. Citizens often dispose of dangerous materials (such as batteries, motor oil, and antibiotics) improperly and those end up in a landfill and can cause serious problems. When water leaches out of the landfill and into groundwater or when gases escape into the atmosphere, those living around the landfill could be in danger. In one case study, scientists found that 15% of small wild animals living near a landfill had resistance to antimicrobials. That means that at least 15% of wild animals come into contact with landfill leachate that has been contaminated with antibiotics (Allen 2010). Landfills can be safe when monitored and cared for; however, accidents do occur that can put humans at risk. To try to reduce that risk, opening and using fewer landfills paired with vermicomposting can help reduce the waste that flows into landfills.

Each city must decide what methods of waste reduction and diversion will work best with their existing infrastructure. In the following case study on Conway, Arkansas, the waste management methods in place are outlined and their similarity to other US cities is discussed.

Conway, Arkansas: Model City

Conway is located in central Arkansas with a population near 60,000 (City of Conway 2012). Compared to the United States as a whole, the city is near the norm on most counts. The average family size in Conway is 3.13, compared to the national 3.25 average. The population in Conway is about 10 years younger, on average, than the rest of the nation. The male to female ratio in both Conway and the country is very similar (about 94 men: 100 women). The median household income in Conway is $44,745 where the median household income in the United States is $50, 502 (United States

Census Bureau 2011). This data is summarized below in Table 1. The city is run by a Mayor and a City Council, all of whom are elected by the citizens. Each of these facts seem to suggest that Conway could be comparable to many other American cities of the same or similar size.

Table 1: Conway, AR as compared to United States as a whole. Statistics from United States Census Bureau 2011.

	Median Age	Family Size	Male:Female	Median Household Income	Land Area	Population Density
Conway, AR	27.6	3.13	91.5 to 100	$44,745	60 mi^2	±1,000/mi^2
Average American City	37.3	3.25	96.8 to 100	$50,502	*	*

*Cities with 60,000 people have population densities ranging from 5.85/mi^2 in Cheyenne, Wyoming to7,800/mi^2 in Monterey Park, California (US Census Bureau 2011) .

Waste-wise the city of Conway is also comparable to many other U.S. cities. Each of the 21,000 homes in Conway is given one 96-gallon trashcan for garbage that is collected weekly (Conway Sanitation 2012). The city has a sanitary landfill (MSWLF) on the outskirts of the city that takes all regulation wastes. It covers 50 acres, though one third of the acreage must be in wetlands (Howard 2013). The city takes in about 500 tons of material each week (Murphy 2013). Recyclables and yard waste have separate pick-up days because they are diverted from the landfill. Conway has a state-of-the-art recycling center. Comingled recycling pick-up takes place weekly for residents. The recycling center can process 1-7 plastics, aluminum, steel, paper, and even Styrofoam (Howard 2013). The city recently began glass recycling. Yard wastes are redirected to an area near the landfill to be mulched and composted, as directed by the Arkansas Department of Environmental Quality. No green yard materials are allowed in Arkansas landfills (Campbell 2013), which saves about 13.4% of the space in a landfill (EPA 2012c).

Yard waste is picked up once a week by a group of 24 employees. The highest intake is in the fall and spring during peak leaf-fall and garden activity. In 2009, the city picked up 11,616,940 pounds of yard waste and in 2010, the intake was 10,754,540 pounds. The leaves, branches, and weeds are mulched using a Morbark 7200 diesel grinder and then lightly composted. The grinder has several sizes of screens, but the most commonly used size is the 1.5-inch screen. The debris is then put into piles to compost; the city employees turn the piles with bulldozers occasionally. Mulched material is made available to citizens for pick up, free of charge. Some of the mulched yard waste is used as alternative daily cover (ADC) material in the landfill instead of soil (Campbell 2013).

The economic cost on the city for yard waste pick-up is very high. Rather than collecting all types of waste in one truck, the separation means a whole set of employees and trucks must be dedicated to the job of yard waste pick up. Conway has some garbage trucks that are automated and require only a driver rather than an extra employee (or two) to unload trashcans into the truck. However, for organic waste pick-up, no such trucks exist. At least two employees are required because one (or both) must manually load the yard waste into the back of the truck. This process can take many hours: three collection trucks work forty hours a week, each covering 8,733 homes and two chipper trucks also work forty hours a week, covering 13,100 residences each. The maximum allowable amount of yard waste per residence is sizeable. Up to ten 30-gallon bags or reusable containers and a stack of limbs 3 feet X 3 feet X 10 feet is permissible per house. The time needed to load that many containers or limbs into a truck for each residence is quite great and the wages for these hard-working employees can be burdensome on the city budget.[1] For the employees working the three collection trucks, wages are over $77,800 a year and the two chipper trucks have a labor cost of $54,600 each a year. Additionally, four other workers work part time, each earning $14.80/hour. That totals to $388,600 a year in wages. The 2013 budget for Conway was $55,957,065 and the Sanitation Department budget was $8,110,000 (City of Conway, Arkansas 2013). The wages listed above just for yard waste collection account for 20% of the sanitation budget. As much of a weight on the city’s economy as it is, the step is necessary to comply with law (and it helps the environment!) because the Arkansas Department of Environmental Quality does not allow green material to be placed in a landfill (unless mulched and used as daily cover) (Campbell 2013).

All sewage waste in Conway is handled by Conway Corporation. Conway Corporation is owned by the city and it runs the electric utilities and treats wastewater and sewage sludge (Conway Corporation 2012). All

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[1] Duane Campbell, manager at the Conway Sanitation Department, mentioned the idea of converting yard-waste pick-up trucks to the automated type to save time and wages, but the initial cost is steep and it would replace at least 12 employees, a move that few, if any, elected officials would be willing to do in the current economy.

sewage waste, including everything from toilets, drains, and sink garbage disposals, goes to one of two sewage and wastewater treatment plants to be separated[2]. Each day, each plant processes about six million gallons of raw wastewater. Of that, about 22,000 pounds of dry solids are removed (McDaniel 2013). All of the wastewater is pumped into large primary clarifier tanks and anything that settles down to the bottom is termed “sewage sludge” and is pumped to other tanks.[3] The sludge mix is aerated for about 6-10 hours. Then, gas-powered heat is applied at 95˚F and the sludge is allowed time to be processed anaerobically by all of the microorganisms already present in it. Two main types of bacteria are present: the “acid producers” and the “methane formers,” as they are called at the treatment plant. A balance must be made between the two types to keep pH around 7.0; to do so, the population of “acid formers” must not be significantly higher than the archaea or “methane formers.” The sludge stays in the

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[2] Previous to the 1980s, all sewage sludge was pumped directly into nearby streams and rivers with no prior processing. Following the Clean Water Act, the city built a single lagoon to let sludge settle out and the floating wastewater to be pumped out and sanitized. Finally, in the 1980s, the Stone Dam Road treatment plant was built and included an aerated lagoon that could hold more. The sludge was still just allowed to sit until it had degraded. Anaerobic digesting of sewage sludge was later added to the Stone Dam Road plant in the early 1990s, earning it the current title of a conventional activated sludge plant.

[3] Before entering the clarifier tanks, large, non-organic rubbish such as plastic applicators from faucets, stones, rags, or concrete is extracted by a series of screens that hold back anything with a specific gravity greater than 2.9 (roughly equivalent to any material heavier than aluminum, but lighter than table salt) (McDaniel 2013).

primary digester for 20-25 days. To meet EPA standards for Class B sludge, the mix must stay at or above 95˚F for 15 days. Class B sludges can contain trace amounts of pathogens but is considered safe for crop application (EPA 2012d). After the 20-25 days are up, the sludge is pumped to the secondary digester, which allows the bacteria to process the sludge more, but is primarily a holding tank. By this time, the original volume of sludge has been reduced 60-80% through the removal of water and the breakdown of large particles by the bacteria. From there, the waste is pumped into trucks and then sprayed on EPA permitted land surrounding the city. The spray consists of about 3% solids and has a syrup-y consistency. About 749 acres are permitted and most of that area is in hay production. The land is privately owned and the owner feeds the hay to his livestock (Lieblong 2013). The Arkansas Department of Environmental Quality (ADEQ) tests the soil of each land plot yearly to be sure there is no dangerous bacterial contamination or too much of any one nutrient that could cause a problem, such as nitrogen, phosphorous, or potassium (McDaniel 2013). The land must fall within EPA regulations as well and those laws, found in 40 CFR Part 503, govern the amount of pathogens and heavy metals that can be found in the sludge, as well as rules for site and crop harvesting restrictions (EPA 2012d).

Currently, only a small amount of sewage sludge from Conway is placed in a landfill. Sometimes sludge does get landfilled when the land is too wet to apply sludge with trucks. In that case, the sludge is laid out in long drying beds, where water is drained off through sand and evaporated by the sun. Then, employees manually shovel the dried waste into trucks that take it to the landfill; the waste is not classified as hazardous because it has been stabilized. Last year 22.5 metric tons of biosolids were discarded in the landfill, which is less than 1% of total waste for the year (Lieblong 2013). The only other things taken to the landfill are any debris sorted out of the wastewater in the initial filtration system as it comes into the treatment plant, which is necessary to remove non-biodegradable objects so that the sludge can eventually be land applied (McDaniel 2013).

The cities of the United States employ many methods of sewage waste treatment and disposal, though the EPA does not keep track of each city's method. Many other cities in the United States dispose of sewage sludge similarly to Conway while others use different methods such as incineration or stabilization and disposal into a monofill. Other cities are on the forefront of innovation. California is an example of a state that utilizes many options, with varying degrees of success. Their recycling campaign, CalRecycle, has many components, one of which is the environmentally sound disposal of sewage waste. In California, sewage waste is disposed of in the following ways: 54% is land applied, 16% is composted, 12% is used as alternative daily cover in landfills, 6% is landfilled, 4% is surface disposed, 5% is incinerated, and 3% is stored short-term in lagoons. Of the wastes that are put back into the environment, all have reached a Class B stabilization rating

(CalRecycle 2008). The 54% that is land applied is treated very similarly to the way Conway processes sludge. The composting programs in California mix the sludge with a bulking agent such as sawdust or with existing green material waste (CalRecycle 2008). Composting is not considered an ideal situation by the state both because the market for composted materials is variable and hard to predict and a large amount of land must be dedicated. The 12% of waste that is used as alternative daily cover (ADC) for landfills means it is used instead of soil to top off the day's wastes. Only three landfills in California, of the 161 active landfills, regularly accept biosolids as alternative daily cover, landfill material, or incinerated ash. Incineration and landfilling are not considered a "widespread management option" in California because the nutrients are not being returned to the Earth and landfill space is wasted (CalRecycle 2008).

The costs of each type of disposal vary and Conway should consider these in comparison to the cost of vermicomposting. Incinerators are expensive and require upkeep as well as have the hazardous effect of concentrating heavy metals in the sludge into the ash that is eventually buried in a landfill (that could potentially leach out).[4] Landfilling sewage

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[4] Several famous ash disasters are known in the United States. The largest catastrophe occurred in Tennesse when a dam holding back coal fly ash broke and released 300 million gallons of ash and water, destroying homes and posing significant enviornmental and human health risks. Ash contains concentrated heavy metals and carcinogens that are a health risk to humans and animals nearby (Dewan 2008).

wastes is not cost effective either; the nutrients that could have been used elsewhere are sequestered while taking up space that costs $35/cubic foot in Conway- and even higher in bigger cities (Howard 2013)! Stabilizing and land applying the waste is the most initially cost-effective solution for most cities because land and equipment is not needed to create a landfill or monofill nor do incinerators need to be purchased. Sewage sludge can be applied to land that the city does not own, as in the case of Conway (Lieblong 2013). However, the nutrient values and cost return on any of those processes are different than with vermicomposting. Land costs in California are definitely high, but in a smaller, more rural city like Conway, land costs are much more reasonable. In areas around Conway, land costs between $6,000 and $17,000 an acre (LandWatch 2013). A few acres could be purchased for the vermicomposting lots without putting a huge dent in the city budget. The section “Conway, AR: Case Study” will discuss the economic pros and cons of vermicomposting further.

Conway is an example of the way many cities dispose of both municipal solid waste and sewage sludge. As with all things, there are high and low points, environmentally and economically. For example, Conway does make mulch of yard wastes and returns it to citizens, keeping that material out of the landfill and in the nutrient cycle. Unfortunately, all household organic wastes such as food scraps are put into the landfill, seemingly defying the ADEQ’s (Arkansas Department of Environmental

Quality) regulation against green material in a landfill. (However, no regulations exist in Arkansas mandating separation of food.) Economically, the current system is cost effective in the short term. Separating yard wastes so that they don't take up space in the landfill is economical. Landfill space in Conway costs about $30-35/cubic foot, so keeping any amount of materials out is desirable (Howard 2013). Comingling food with trash is easier in the short term, though, because it is cheaper than developing and executing educational programs about the benefits and methods of vermicomposting to inform citizens. Nevertheless, many economic and environmental externalities come into play with this method. Dumping food into the landfill means that the landfill will fill up faster and require closing costs, which can be upwards of $100,000 an acre (Maryland Department of the Environment). The Conway landfill is about 35 acres; undoubtedly, the incentive to keep it open and available as long as possible is strong (Howard 2013). In addition, more land and materials will be necessary to build a new landfill. By diverting food scraps, which take up 13.9% of a landfill, the landfill can stay open longer to house non-recyclables and non-compostables (EPA 2012c).

The Science Behind Vermicomposting

Vermicomposting is the utilization of Earthworms to digest organic wastes and excrete them as valuable Earthworm castings. Both Earthworms and microorganisms work together to produce the end product, which is nutrient-rich, environmentally stable, and pathogen-free organic mixture of humus and vermicastings that can be applied to agricultural fields, livestock pastures, and home gardens. Any type of organic waste, excluding meat and dairy products, but including human excrement, can be processed by the worms (Applehof 1982). The process takes the same amount of time as most conventional waste management procedures such as anaerobic digestion or hot composting. Worms can convert organic waste into vermicompost at a rate of 0.45 kg waste per 1.0 kg Earthworms (Yadav 2011). The end product particle size is typically very fine and thus able to hold significant moisture, bind organic nutrients, and become an accessible food source to microorganisms. The small particle size allows moisture retention through the forces of adhesion and cohesion as water forms a thick film on the soil particle surfaces. This water is accessible to plant roots long after the majority of water has sunk into the soil with gravity. In soils with larger soil particles, there is less surface area for water to cling (Lowenfels and Lewis 2010).

Nutrients in vermicompost are “plant-available” or “bio-available” meaning their chemical form is one that plants can readily use. Vermicompost has humus, a complex material formed during the decomposition of organic matter. Humus releases humic acid, which is negatively charged and so provides binding sites for calcium, iron, potassium, magnesium, and sodium, all of which have a positive charge[5]. Each of those nutrients are essential to plant growth and development; plants “eat” the nutrients by exchanging a hydrogen ion on their root hairs for one of the other positively charged elements (Lowenfels and Lewis 2010). In typical soil, even where those nutrients exist, it is harder for plants to take advantage of them because they are not bound to the soil particles and can leach out with water. Humus and clay particles, both in rich abundance in vermicompost, are ideal for binding nutrients because they are small enough to carry an electric charge. (Sand and silt particles, for example, are too large to carry a charge.) Vermicastings have also made their way through the Earthworms’ digestive tracts, meaning the digestive enzymes have broken chemical bonds that prevent nutrients from being bio-available. For example, when Earthworms process nitrogen, their digestive tract converts it to nitrates, the form of nitrogen plants prefer. (With hot composting, nitrogen is converted to ammonium, which plants cannot process as easily (Lowenfels and Lewis 2010).) Thus, vermicasts can have up to seven times more phosphate, five times higher nitrogen, three times more magnesium, and are one and half times higher in calcium than soil that has not passed through an Earthworm (Lowenfels and Lewis 2010). Vermicasts also have few heavy metals, which is especially good when working with sewage sludge. Heavy

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[5] The humus in vermicompost also promotes soil particle aggregation, which improves the permeability of the soil to both water and air (Lowenfels and Lewis 2010).

metals are accumulated in the worms' bodies and those that are excreted have been organically-bound to decrease their water solubility, which makes them safer for the environment (Hait 2012).

Earthworms break down organic matter, increasing the surface area and making the particles very small. This also increases accessibility to microorganisms. Populations of microorganisms rise as more organic matter is broken down to a size they can eat, which is a very good thing. Microorganisms play vital roles in the soil. The bacterial order *Actinomycetales* is one of the most common bacteria found in soil; they produce the volatile chemicals that give "good soil" its rich, Earthy aroma as they break down organic matter. The genus *Cellulomonas* (of the order *Actinomycetales*) can break down cellulose, a major component of plant body mass (Lowenfels and Lewis 2010). When these types of bacteria feed on organic matter, they lock up the nutrients in their bodies. This prevents the loss of nutrients through leaching. When bacteria die or are consumed by larger organisms, like protozoa, the nutrients are released into the soil where root hairs can absorb them (Lowenfels and Lewis 2010).

Vermicomposting is similar to hot composting, where organic wastes are piled up and allowed time to be processed by microorganisms. The microbes heat up the pile with their activity and that heat also helps break down the wastes. The product (from both hot composting and vermicomposting) is a rich organic material. Composted materials tend to have more microorganisms, but fewer nutrients than vermicomposted material, though. That is because the Earthworms eat microorganisms and reduce their numbers. The heat generated from hot composting can burn off nutrients such as carbon and nitrogen in the form of CO_2 and NO_x (Cornell University 2000a). The carbon and especially the nitrogen could have been used by plants had the elements been converted to a bioavailable form, rather than a gas. Thermophilic compost piles can reach internal temperatures between 126˚F and 158˚F for weeks at a time, depending on the size of the pile, which means more and more carbon and nitrogen will turn to the gaseous phase (Schulze 1962). In vermicomposting, the temperature only spikes for a few days and then drops to lower temperatures (Applehof 1982). A constant temperature over 131°F for at least three days is necessary to reduce pathogens (Cornell University 2000a). Overall, both vermicomposting and hot composting are valuable to the Earth and contain important nutrients and microorganisms. The main distinction between them is the reduced time needed to produce and the higher resulting nutrient value of vermicompost.

Vermicompost is a much more environmentally stable option when compared with commercial fertilizers. Most fertilizers can “burn” plants, meaning the synthetic chemicals damage the fine roots (Maryland Cooperative Extension 2009). Because vermicompost is a complex mixture of *natural* materials, chemical burns are not a problem. Vermicompost also contains beneficial microorganisms that work symbiotically with plants to reduce disease. Ohio State University found that crops fertilized with vermicompost are more resistant to blight, bacterial wilt, parasitic nematode attacks and powdery mildew compared to those plants grown with chemical fertilizers (Dunn 2011). Beneficial microorganisms produce antibiotics that can combat plant diseases when a plant absorbs the antibiotics. For example, *Pseudomonas* bacteria create phenazines, a broad-spectrum antibiotic known to combat take-all, a fungal wheat disease (Lowenfels and Lewis 2010). Also, with beneficial bacteria growing quickly and eating large amounts of food, pathogenic bacteria are kept in check. Chemical fertilizers also disrupt the natural cycle of microorganisms and Earthworms eating and excreting organic nutrients by replacing organic nutrients with non-organic ones and changing the natural ratios of each element. Some worms and microbes may die as a result. That means that not only does organic matter on the surface of the soil not get broken down as quickly, but many nutrients in the soil do not pass through the Earthworms' digestive tract and get converted to bio-available nutrients; instead, most nutrients in the soil are not bound to soil particles (such as humus), so the nutrients leach out with water.

Process of Vermicomposting

Almost all yard wastes and many food wastes can be vermicomposted. Exceptions consist of any food that is excessively oily, spicy, salty, hard, or contains meat or diary. Examples include fried or overly processed foods, citrus fruits, and hamburgers. The list might seem restrictive, but that still allows for all fruit and vegetable scraps (including peels, rinds, cuttings, and extra bits), dry cereals, and miscellaneous foods such as coffee grounds and tea leaves. Yard wastes including grass clippings, tree limbs, leaves, weeds, and dead plants may all undergo vermicomposting (Appelhof 1982). Preferably, the clippings should not have come into contact with chemical pesticides, herbicides, or fertilizers. Presumably, Earthworms can handle a small amount of any of those, but there is a threshold limit where Earthworms will begin to die when contact is made with those types of chemicals. However, many modern pesticides have very short half-lives in water or soil and clippings treated with those might be suitable for vermicomposting due to the high heat in the thermophilic phase**.** Yard wastes that have not been treated at all or have been treated with quickly-degrading chemicals, as well as vegetables and fruits that have only been boiled, steamed, or lightly seasoned all make up valuable vermicomposting substrate.

The most common home pesticide used in private yards is imidacloprid (Cox 2001). Commonly marketed by Bayer, the chemical is “used in the greatest volume globally of all insecticides” (Cox 2001). This chemical is acutely toxic to Earthworms. The LC_{50} for one species of Earthworm, *Eisenia fetida,* is only 2-4 ppm in soil. The ability of the worm to breakdown plant material is hindered at a concentration of only 0.2 ppm in soil (Cox 2001). The half-life of imidacloprid varies in differing environments, but the quickest half-life was still three months on turf. It is unclear how this would extrapolate to its persistence on plant material in a compost pile, but even if the breakdown was sped up, *E. fetida* can handle only a very, very small concentration (Cox 2001). Presumably the pesticides used in agriculture around Conway would not make their way into the vermicompost, but in the early stages of the program, special attention needs to be paid to this threat.

For efficient vermicomposting, specific types of Earthworms are superior to others. Epigeic Earthworms are the best for the job because they live on the surface, tend to move horizontally through the soil, do not create burrows, and feed on surface litter. All of those characteristics are important because the worms need to eat food that is near the surface, live in a small vicinity, and not be upset by soil disturbance that would destroy any burrows (Appelhof 1982). The most commonly used epigeic vermicompost worm in the United States is *Eisenia fetida,* pictured in Figure 4. The worm is not native to the Americas, but has been introduced to every continent but Antarctica. Common names for the worm are “red wigglers” and “night crawlers.” The worms are characterized by a brown color with light brown stripes, a life cycle of 45-51 days, and an average weight of half a gram. Earthworms prefer a temperature between 40˚ and 90˚F, a moisture level between 70% and 90%, and pH between 5 and 9 (Appelhof 1982). They have a high rate of consumption and digestion: each Earthworm can eat half its body weight a day. *E. fetida* also reproduce quickly (doubling every three months) and are able to tolerate environmental stresses such as temperature or moisture level change and many of them can live in a very small area (Singh 2011).

Figure 4: E. fetida pictured with ruler and up close. Photo on left courtesy vermicomposters.com. Photo on right courtesy of RedWormsComposting.com.

The appropriate stocking density and feedstock rate for worms to be able to consume the largest amount of food without slowing down reproduction rates has been studied in several ways. A 2011 study done in India by Yadav and associates found that the optimal stocking density of worms for the fastest Earthworm reproduction and growth was 0.50 kg-Earthworm/m^2. Surprisingly, the study found that a stocking density of 3.0 kg-Earthworms/m^2 allowed for the highest conversion of feedstock to vermicastings. These numbers reflect those densities that do not have an associated loss of Earthworm biomass; it is important that the worms are not cramped or they will lose body mass and produce smaller offspring, meaning they will eat less overall[6]. A density between these two disparate numbers would be ideal to balance growth and reproduction with the desired quick conversion of waste to vermicasts. The amount of food given to the worms at a time is also important. Most literature reports a food consumption rate between 0.5 and 1.0 kg-feed/kg-Earthworm/day (Sherman 2011). Yadav found that for optimal food intake by worms, a feedstock rate between 0.40-0.45 kg-feed/kg-Earthworm/day was most advantageous. Stocking worms at 2.5 kg-Earthworms/m^2 and feeding at a rate of 0.45 kg-feed/kg-Earthworm/day seems to be the best and fastest way to convert food to soil (Yadav 2011).

In large-scale vermicomposting, the daily organic waste intake, or the feedstock rate, could fluctuate each day but would remain mostly stable over time. Predictable increases and decreases in intake occur in most cities. For example, in Conway, the model city, waste decreases during the winter holidays (because ~20,000 college students leave town) and waste increases during Toad Suck Daze (a festival the city hosts that draws residents from neighboring areas into town) (Lieblong 2013). Predicting instances such as those would allow the vermicomposting to continue rather unaffected. If the vermicompost piles were outside, the fact that winter food

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[6] A density of 4.0 kg/m^2 produces an even higher production of vermicast, but with an associated loss of individual Earthworm biomass; it was ruled unsustainable (Yadav 2011).

decreases occur would be okay because worms move slower and eat less when the temperature is low.

Giving the worms too much food at once causes the food to start molding and souring, creating conditions inhospitable for Earthworms. Adding food day to a small initial pile would be the most advantageous course of action. About six inches of materials should be added per day to keep the feedstock rate in range and to keep the food from crushing the worms. Epigeic worms like to live near the surface, so adding too much food might mean food lower in the pile would not get eaten. Of course, depending on the weight and condition of the waste (how decomposed it is), the process could deviate from the predicted consumption rate of 0.45 kg food/1.0 kg earthworm/day. Also, in large piles with lots of worms, the worms would reproduce and eat the food faster than the original population alone. Making the pits a uniform size and taking the reproductive rate of *E. fetida* into account would make it easy to know how many worms to add to each pile.

For sewage sludge to be vermicomposted, it must be mixed with brown materials high in carbon. Sewage sludge is high in nitrogen. To have a balanced vermicompost pile, the C:N (carbon:nitrogen) ratio must be about 30:1. Without this ratio, microbial life will not do well. Low nitrogen content will be a limiting factor to microbial populations and slow the decomposition rate. Too much nitrogen will cause microbial populations to grow rapidly and begin using up all of the oxygen, creating anaerobic conditions, which are not beneficial to the microbes, the decomposition process, or the Earthworms. Ammonia gas may be given off in these conditions, allowing a valuable source of soil nitrogen to go to waste (Cornell University 2000b). Table 2 below outlines the various materials that can be used for “worm food.” Mixing materials to achieve a ratio around 30:1 is ideal, though its not always straightforward. Some materials are less “bioavailable” than other; for example, wood chips must be broken down to release the available carbon stores. In this case, more carbon might need to be added to the pile to be sure the nitrogen level is not too high (Cornell University 2000b).

Table 2: C:N ratio of various vermicompostable materials. Courtesy Cornell University/Tom Richards.

High Nitrogen Materials:	**C:N**
Grass Clippings	19:1
Sewage Sludge (digested)	16:1
Food Wastes	15:1
Cow Manure	20:1
Horse Manure	25:1
High Carbon Materials:	
Leaves and Foliage	40-80:1
Bark	100-130:1
Paper	170:1
Wood and Sawdust	300-700:1

A major infrastructure change would have to be implemented in Conway to covert to sewage sludge/food waste vermicomposting. First, the wastes would need to be allowed to thermophilically compost (“hot composting”). Thermophilic composting occurs when bacteria begin breaking down the organic matter and thus create heat. Thermophilically composting the mixture for at least a week would allow the wastes to start breaking down and to kill off all human pathogens and weed seeds from the yard waste with the intense heat generated. A pile heated to 131˚F (55˚C) for at least three days kills pathogens (Cornell University 2000a). This process could take place in piles on top of the ground or in pits dug for the purpose. Many piles or pits would be necessary so that a continuous cycle can occur, with piles maturing and being moved to a new area for vermicomposting. Once hot composted, the waste would be added slowly- about six inches per day- to the top of vermicompost piles to allow the worms time to process the food before more is added.

To tackle the difficult infrastructure changes, several pieces of equipment would need to be purchased. Some type of turning device, whether a mechanical compost windrow turner or just a front-end loader, would have to be used to turn the piles after a week of thermophilic composting. Front-end loaders could also be used to add worms to the new piles and remove them. To do so, the front-end loader would need to scoop up mature vermicompost and dump it into a commercial mechanical worm harvester. These devices usually work with a long, vibrating belt onto which the vermicompost is shoveled. The belt is made of small mesh that allows vermicompost particles to fall through, while worms are left to ride to the end of the belt, where they fall into a receptacle. From there, the worms (as well as any large, undigested food particles that could not fall through the mesh) can be added to a new pile, while the vermicompost below is ready to bag and sell. By using a mechanical harvester, the vermicompost has been screened to get rid of large particles, which increases the value of the product, and almost all of the worms are removed (Vermiculture Canada). There is no efficient way to remove worm cocoons from the vermicompost, unfortunately. It does fortify the vermicompost product, though, because gardeners will be happy to have some new worms in their compost. Figure 5 below shows an example of a commercial mechanical Earthworm harvester.

Figure 5: Commercial mechanical worm harvester. The vermicompost is added to the left end, travels down the belt, and falls through the mesh into buckets below. Worms remain on the belt and are deposited into the green bucket at the right end. Photo courtesy Vermiculture Canada.

Some cities may decide that changing the infrastructure to re-route sewage sludge to new areas of the city is too high and decide instead to vermicompost only food and yard wastes. The process would be similar: mix brown and green materials to reach a C:N near 30:1; allow it to thermophilically compost for 5 days; turn; add worms to a new pile; add more feedstock each day; harvest worms; repeat the process. This protocol follows the general guidelines used for small-scale vermicomposting; private vermicompost companies do not release their protocols so the city must infer the process. The smell generated from this yard and food waste only operation would be much less offensive and it would be a lower cost because of the reduced volume. Fewer employees, land, and equipment would be necessary to vermicompost only food and yard wastes. Therefore, a city might try this method first to train employees and buy equipment in increments, rather than all at once as would be necessary when working with sewage sludge.

Technical and Scientific Challenges

A possible hardship for both programs (food and yard wastes combined with *or* without sewage sludge) is the necessity of food waste sorting. Families and companies would need to be willing to source-separate compostable foods from their garbage. Many families across the world separate out their organic wastes, including American families, and the process takes very little extra time. Dairy and meat products would have to be sorted from the rest of food wastes; worms cannot process those foods well because the breakdown is so slow and the smell escalates quickly. In small quantities, meat and dairy goods could be processed by the worms, but in large amounts, they would produce odiferous smells as well as cause other serious problems with mold. The key to this problem is to work proactively and provide education to the city about what can be vermicomposted and what is best left in the trashcan. However, if those efforts do not prove to be effective, an impasse is reached. Further options include sustained education, non-removal of unsorted curbside wastes, and/or fines for households that improperly sort wastes. Over time, though, if noncompliance continued, the city might have to revert back to collecting only yard wastes and vermicomposting it alone. This is discussed further in the next section, “Adaptations for Public Participation.”

When vermicomposting sewage sludge, many scientific challenges exist. Most studies undertaken on excrement vermicomposting have been conducted in small villages around the world, where composting toilets[7] are the norm and plumbing does not exist. For example, the study by Yadav and colleagues to determine the appropriate worm and feed stock densities used human excrement from a small village that used “a non-flush, drop and store type of toilet [with] separate seats for defecation and anal cleaning” (Yadav 2011). As such, the researchers did not have to contend with problems Americans would face in launching a vermicompost program. The main concerns with American plumbing include the extensive amount of toilet paper, excess toilet water, and toilet cleaning chemicals. Many households

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[7] A composting toilet is built into the ground and allows excrement to breakdown aerobically. Typically they require little maintenance besides adding sawdust to decrease odors and increase the carbon content to improve conditions for microbial life.

use bleach to clean the toilet or have a time-release bleach tablet in the bowl that emits a stream of bleach with each flush. Even when bleach is not used, other toilet cleaning chemicals would be harmful to Earthworms. Little scientific research bearing on this subject has been conducted and the minimum harmful threshold of these chemicals to worms is unknown. Toilet paper, surprisingly, also poses a health risk to the worms. The paper itself is not the problem: that can be processed by the worms. The issue is that most toilet paper has been bleached to reach its pristine white color. It is possible the heat generated in the thermophilic phase would ameliorate these problems by breaking down the bleach and evaporating water. However, since this has not been studied, the amount of bleach left in the toilet paper and the cleaning products in the waste are two problems with uncertain outcomes.

Finally, the large amounts of antibiotics and prescriptions that Americans ingest eventually make their way out of the body through urine and feces. Again, few studies have been done on the effects of antibiotics on Earthworms. Almost no studies have been done using the full spectrum of medicines likely found in a mixture of American sewage sludge to determine the thresholds for harm and the interactions between drugs that could be harmful to Earthworms. Some areas of the United States might differ in the amount and types of antibiotics found in the sewage sludge. For examples, communities with high meat and dairy intake would likely have higher rates of antibiotics because of the overuse of antibiotics in conventional livestock rearing. Over 80% of antibiotics used in America go to livestock (Tavernise 2012). Rural cities that rely on meat and dairy grown on farms nearby might have lower antibiotic rates in sewage sludge. It is also unknown how much antibiotic would be present in sewage sludge that has both traveled through a human body and undergone thermophilic composting. Most antibiotics are meant to be stored between 58 and 86°F, so it is plausible that the drug would breakdown with thermophilic temperatures up to 131°F (Konrad 2011). However, some chemical changes at high temperatures cause drugs to become harmful to human health (Konrad 2011). These uncertainties might pose a risk to Earthworms and further investigation needs to be done before implementing this on a large-scale.

Adaptations for Public Participation

The public must separate their wastes to be able to vermicompost food scraps. Already, at least 25% of Americans do not sort recyclables at all in their homes. Of those that do recycle, about 77% recycle aluminum cans, 67% recycle paper, and 59% recycle plastic (Harris Interactive 2007). Even with 75% of the United States recycling, approximately 40-50% of material found in landfills could have been recycled (EPA 2012c). Getting Americans on board with separating yet another waste- food scraps- would be quite a task. Understanding the barriers that hold people back from separating wastes is important. Elizabeth J. O’Connell laid out several motives for why citizens do not recycle in her article “Increasing Public Participation in Municipal Solid Waste Reduction” (O’Connell 2011). One of the main reasons she found that people do not separate wastes is the lack of access to recycling (or composting) facilities or the inadequacy of those that exist. Following closely behind is the absence of knowledge about what can be recycled as well as the perceived inconvenience of sorting wastes. To combat those problems, O’Connell suggested working to change social norms associated with waste, educating people about the environment and the proper procedures for recycling, touting the benefits of recycling, and providing convenient access to facilities for all citizens (O’Connell 2011). All of those are easily transferrable to the composting and vermicomposting movement. Shadowing the types of programs introducing recycling in the 1990s, many of which followed the ideas above, could be a step in the right direction for a vermicomposting program.

In *Beyond 40 Percent,* Brenda Platt and her colleagues assessed various recycling and composting programs across the United States during the mid- to late-1980s (Platt 1991). As expected, those communities that had mandatory recycling programs had the highest rates of material recovery. Mandatory programs with some type of enforcement policy, such as refusing to pick up rubbish with recyclables in them or assessing a fine for noncompliance, had the highest recycling and composting rate. Examples of some of these cities include Haddonfield, NJ (where the number of recycling houses rose 53% for newspaper and 153% for glass after the introduction of mandatory recycling) and Fennimore, WI (which has a 100% recycling participation rate) (Platt et al. 1991). Those cities that did not have mandatory recycling but still managed high levels of participation often had strong incentives for recycling. For example, volume-based rates for waste collection and curbside pick-up of only recyclables powerfully encouraged residents to sort their wastes (Platt et al. 1991).

Platt also found that communities with larger populations tend to generate more commercial than residential waste. Commercial waste was defined as waste generated by businesses and institutions such as schools and government buildings as well as construction debris. Almost all commercial buildings have some amount of organic waste output. For example, hotels and restaurants have food wastes, schools serve lunches (as well as some corporate buildings), and landscaping businesses acquire huge amounts of plant material that must be disposed of somehow. Creating some type of incentive for participation (or consequence for nonparticipation) to get commercial entities to compost would be an important aspect of a new vermicompost program. More wastes could be gathered at one point and it would encourage the employees of the building to compost their organic wastes at home as well.

The frequency of pick-up was a major factor in the amount that citizens recycled in Platt's case studies. Weekly pick-up of recyclables tended to have a 91% participation rate, whereas bi-weekly collection had an average participation around 81% (Platt 1991). One case study focused on Seattle, WA in the mid-1980s. The northern section of the city had weekly pick up and a participation of 90% while the southern portion of the city had a monthly pick up and only 67% participation (Platt 1991). In addition, the northern households recycled 18% more materials than the equivalent southern households (Platt 1991). Weekly compost pick-up would be the most beneficial for most cities both to increase participation and to prevent undesirable smells.

One city that is on the forefront of U.S. environmentally proactive cities is San Francisco. The city pledges to be “zero waste” by 2020. That means that all waste will be reused, recycled, or composted and nothing will go to a landfill or incinerator (SF Environment). The policy sounds difficult to implement, but so far the city has been met with success. The city implemented their “Mandatory Recycling and Composting Ordinance” in 2009 and recycling rates went from 46% to 78% in one year. The next year, in 2010, recycling rates were up to 80% (SF Environment). The city also implemented a website called “RecycleWhere?” that can direct residents where to take any item they need to get rid of, from couches to batteries to tires. While San Francisco does not vermicompost their organic wastes, the city does compost all green waste. The policies that San Francisco has implemented to encourage source-separation of wastes could be in important example that other cities can utilize when setting up a new vermicomposting program. Some of these policies include a huge educational campaign preceding the switch, fines for noncompliance, and distribution of new collection bins to remind citizens of the policy (SF Environment). In the case study on Fennimore, Wisconsin in Platt’s book, the city encouraged the new mandatory recycling program with newspaper articles, radio ads, open houses at the Recycling Center, flyers enclosed with utility bills, and programs for children (Platt 1991). Any press for a new vermicomposting program would be important to get the program rolling and in the public eye…and hopefully in public participation.

Implementation in Conway: Case Study

Each day, on average, Conway produces 22,000 pounds of dry biosolids (McDaniel 2013), 30,645 pounds of yard waste (Campbell 2013), and 20,000 pounds of food waste (Murphy 2013). Together, the waste totals 72,645 pounds a day of vermicompostable waste. The proper ratio of food to worms is 1 lb-worms/2.2 lb-food (Yadav 2011). That means the city would need 159,819 pounds of worms to process one day’s worth of waste! That much waste is a volume of 129 cubic yards (calculated using conversion table from New Mexico Environment Department). The product from vermicomposting sewage sludge, yard, and food wastes would be a nutrient-rich product that sells for $330/square yard commercially (Red Worm 2013). Though the mass will shrink during the decomposition phase, even if 40% of the mass is left and it was sold at $300/cubic yard, the sellable amount per day would equal $15,543![8] If only food and yard wastes were vermicomposted, the product would still bring in $12,720 per day. It would also save the city money on fertilizer and potting soil in city parks and gardens.

The main four components of implementing a vermicompost program in Conway are: equipment, land, costs, and participation. Equipment would have to be purchased and some existing machinery might need to be modified or moved around. In addition, the sewage sludge would have to make its way from the current waste treatment plant to the vermicomposting site. No infrastructure exists to carry 22,000 pounds of dry wastes away from the plant at this time and the ability to change it is uncertain at this time. Additionally, pits would have to be built, requiring some serious machinery and labor. Front-end loaders are necessary to move waste into the pits as well as turn the piles as well as move it to the vermicompost pile. At least one or more automatic mechanical worm harvester would be necessary. New types of waste pick-up bins need to be made available to households to hold yard and food wastes. For example,

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[8] 20,000 pounds of food waste a day converts to square yards is ~18.7 yd^3. The 30,645 pounds of yard waste per day converts to ~87.5 yd^3. Sewage sludge per day is 23yd^3 in Conway. Added together and reduced to 40% of the original mass, the remaining product would be about 52 yd^3 produced a day. Calculations made with conversion table from New Mexico Environment Department.

bins with locking lids would be helpful for keeping out scavenging animals trying to eat the food scraps. As these bins are distributed to houses, educational materials can also be delivered. New waste pick-up trucks would almost definitely be necessary to accommodate the increased amount of waste on yard waste/food scraps pick-up days. That also requires more employees, not only because there would be more waste per house but also because more houses and businesses will be added to the routes that do not normally set out organic wastes (such as businesses and homes that use yard care services). Once picked up, the food and yard wastes would have to be chipped or shredded. The city already owns a large chipper/shredder, but with the increased volume of waste, another shredder might need to be added. Finally, the city would have to buy worms at a high initial cost. Table 3 outlines some of the costs associated with implementing a vermicomposting system for sewage sludge, yard wastes, and food scraps.

Table 3: Cost Estimates of Start-Up Vermicomposting of Sewage Sludge with food and yard wastes in Conway, AR

Item	Price	Units Needed	Total
Worms	$18/lb	160,000	$2.8 million*
Harvester	TBD	2	TBD
Front End Loader	$125,000	1	$125,000
Land	$7,000/acre	7	$49,000
Chipper/Shredder	Can be leased if necessary	1	TBD
New collection	$35**	21,000	$735,000

bins			
Distribution of new bins and educational materials	$2**	21,000	$42,000
Waste Pick Up trucks	$142,000**	2	$284,000
		Grand Total	**>$4.16 million**

*This number would likely decrease because of the large amount of worms being purchased. Wholesale worm outlets do not publish prices. **These numbers come from CalRecycle 2002.

Changing the infrastructure of the sewage treatment plant would be a much bigger undertaking than rerouting organic waste collection trucks. None of the existing sewage treatment tanks could be utilized unless heavily modified to allow airflow. The best option is to allocate a 5-7 acre lot for the vermicomposting. The city owns some land around the city, but it might be easier to buy one large parcel of land to encompass the whole vermicomposting project and to keep a perimeter around it as a buffer. As mentioned earlier, land around Conway costs between $6,000 and $17,000/acre. Optimistically the city could gain 5-7 acres at a price around $7,000/acre. Of course, the buyers must check on the zoning of any land under consideration. The main problem, more than the cost of land, is how to get the sewage sludge from the existing treatment plant to the new land made for vermicomposting. Some options include rerouting the city’s sewage system or loading the sludge in trucks at the old site and transporting it to the new site. The former is very expensive and the latter is not a long-term solution. Conway would need to hire engineers to look at the problem more closely and to estimate costs- all of which are in addition to the $4.16 million necessary for once the sludge gets to the lot.

Because rerouting the sewage sludge would be such an expensive imposition, it is prudent to look at the costs for vermicomposting just the food and yard wastes. The protocol is similar, as mentioned above in the section “Process of Vermicomposting” on page 32. In Conway, to vermicompost food and yard wastes, 111,419 pounds of worms would be necessary (for the 50,645 pounds of waste per day). The land necessary to house this operation would be 3-5 acres. If the city could find 5 acres together, it would be sensible to buy it as a package. Other equipment costs would be the same. These costs are summed up in Table 4 below. In total, nixing the sewage sludge vermicomposting would save over one million dollars (because the price to reroute sludge is high and unknown).

Table 4: Start-up costs for vermicomposting program for food and yard wastes only in Conway, AR

Item	Price	Units Needed	Total
Worms	$18/lb	111,419	$2 million*
Harvester	TBD	2	TBD
Front End Loader	$125,000	1	$125,000
Land	$7,000/acre	3	$21,000
Chipper/Shredder	Can be leased if necessary	1	TBD
New collection bins	$35**	21,000	$735,000
Distribution of new bins and educational materials	$2**	21,000	$42,000
Waste Pick Up trucks	$142,000**	2	$284,000
		Grand Total	**>$3.2 million**

*This number would likely decrease because of the large amount of worms being purchased. Wholesale worm outlets do not publish prices. **These numbers come from CalRecycle 2002.

Spending $3 million might still seem like a rash plan, but the city would recoup their initial investment in about a year. If the vermicompost did sell for $12,720 per day, the initial $3 million investment would be recovered in 252 days! Of course, in the pilot year of the program, this efficiency is not expected, but in a year or two the program should start profiting. The funds could be saved to reroute the sewage sludge in the future. A steady market for vermicompost is a must and could be difficult to find at first, but would be well worth the time spent searching for it once profits started coming in.

One final option for the city of Conway is to vermicompost food and yard wastes with the sewage sludge that is currently being put in the landfill (because conditions are too wet to spray it on land). That amount only totals 22.5 metric tons of biosolids per year (less than 1% of total sewage sludge) but would be step in a more sustainable direction as well as an easy way to “test” vermicomposting of sewage sludge (Lieblong 2013). That amount of waste is 52.5 cubic yards per year, which is less than the total yard waste picked up per day. That amount of sludge takes up 1,409 ft^3 in the landfill; at $35 a cubic foot, that waste costs the city $49,329 a year! While a large amount in the landfill, it is a small amount for the vermicompost system, so the total cost would not change- except to go down almost $50,000.

Conclusions and Discussion

After a comprehensive review of the sewage and wastewater treatment plants in Conway as well as the yard waste and garbage collection methods, the most environmentally and economically feasible plan would add the sewage sludge currently being put in the landfill to the food and yard wastes for vermicomposting. This method seems highly doable and rather straightforward. Changing the entire infrastructure of the sewage treatment plant and hiring engineers and laborers would prove to be an economic hardship. However, educating and encouraging citizens to add food scraps to their existing yard waste would help divert at least some of the 13.9% of waste in a landfill made up of food. From there, the city might be able to add sewage sludge vermicomposting in the future. If the city did not invest in vermicomposting for the food wastes, the city would be voluntarily allowing the landfill to fill up sooner than necessary- about 14% sooner! The costs to cap the Conway landfill are between $2,800,000 and $17,500,000 (Maryland Department of the Environment)--certainly a strain on the Sanitation Department’s budget of $8 million a year. Though it would require $3 million to start a vermicompost program in Conway, the city budget would reap benefits for years to come and the environment would be healthier with the nutrients back in their place in the ecosystem and without methane, carbon dioxide, and ammonia rising from the organic wastes in the landfill.

In other cities similar to Conway, the cost would be assumed to be similar. However, cities that are more urban or more highly populated might have trouble finding land as cheaply and wages for employees could be higher. More rural or smaller cities might have to spend large amounts of time picking up organic wastes from houses that are farther apart. In those cities that already have a separate yard waste pick-up route, the process would be much easier. For those that do not already separate yard wastes, the cost would be higher because the city would have to start by adding new bins, trucks, and employees to pick up yard waste separately. In addition, the community would have to launch an educational campaign about separating yard wastes and about vermicomposting. Cities could try to overcome their obstacles by starting a pilot program in a few neighborhoods to assess the success of the program and learn from mistakes early.

Each city must decide whether a vermicompost system is feasible with their budget and available resources, being careful to consider the costs to the environment of not acting to repair the nutrient cycle. Different methods and machinery can be used to achieve the final end product that is favorable for environmental and human health in the short- and long-term. In the short-term, landfills will stay open longer and fewer chemical fertilizers will be necessary. Long-term benefits include the replenishment of topsoil (rather than its continued loss), fewer greenhouse gases being emitted from landfills, and nutrients will be recycled to their place in ecosystems. All of these are important for the Earth and therefore are also advantageous to humans. The program will pay for itself, if not profit, in a few years in most cities. The initial investment is great, but would in turn produce great results. Worming our way to a greener future has many variables and uncertainties, but with all noble undertakings, there is hope for a better future.

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