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Urban Food-Waste-to-Compost Conversion System

BIOLOGICAL SYSTEMS ENGINEERING
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KEYWORDS

World hunger; Food waste; Food loss; Global Warming Potential; Food compost; Urban composting; Milwaukee; Municipal compost; Soil amendment.

STATEMENT OF NEED

The amount of food Americans discard is shocking. In 2014, more than 38 million tons of food waste was generated, with only 5 percent diverted from landfills and incinerators for composting (EPA 2014). The Environmental Protection Agency (EPA) estimates that food waste constitutes 21.6 percent of discarded municipal solid waste, and that more food reaches landfills than any other single material (see *Figure 2*.) (EPA 2014). Globally, the statistics do not differ much from the current state of food waste in America; nearly one-third of the food produced in the world is wasted, compared to 40 percent in America.

The United Nations estimates that 795 million people, one in nine, do not have access to a sufficient amount of food to lead a healthy life (World Food Programme 2008). Furthermore, one in three suffer from malnutrition, a leading cause of death in impoverished areas. Food wastage is not only morally irresponsible, but also causes major economic losses as well as severe damage to the environment. *Figure 1*. (right) portrays the dominance of malnutrition-related deaths to ten leading causes of death.

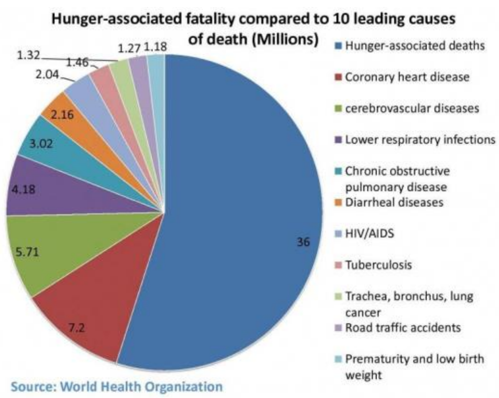

Figure 1. Hunger-associated fatality compared to 10 leading causes of death (retrieved from http://www1.wfp.org/)

Food wastage includes food loss during upstream production, yield handling and storage phases in addition to food waste during downstream processing, distribution, and consumption phases (Balk 2005). The Food and Agriculture Organization reports that while higher and middle income regions showed greater food waste during downstream and consumption phases, developing countries had greater food loss during upstream processing due to lack of proper harvest techniques and technology (FAO 2017).

The decomposition of food waste in landfills generates methane, a green-house gas with twenty-one times the global warming potential to that of carbon dioxide (Greenhouse Gas Protocol 2007). Food waste also represents a major waste of ground water resources and energy accounted for throughout production and processing. According to the U.S. Department of Agriculture, agriculture demands over 70 percent of the world's water usage (USDA 2017).

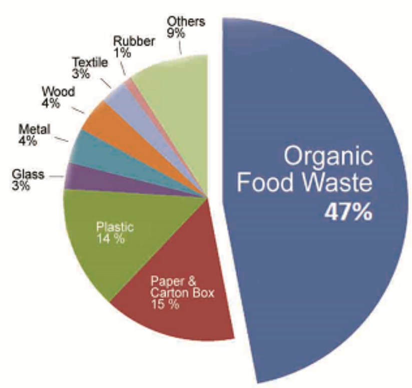

Figure 2. Types of waste in America (retrieved from https://www.usda.gov/)

While efforts must be made to reduce food waste on a global scale, food composting represents an environmentally beneficial solution. Composting diverts food waste from landfills and converts it into a nutrient-rich soil amendment. Composting provides a number of benefits to the soil. Composting serves as a natural fertilizer and pesticide, reduces erosion and

nutrient run-off, and restores nutrient capacities in the soil (McLatchey et al. 1998).
As Tom Philpott wrote in an introductory essay to Grist's Feeding the City series, urban agriculture took a huge hut once combustible-fuel machines replaced horses, and horse manure, as the vehicle of choice in cities (Hanson 2009). If provided the means, city dwellers can help divert tons of organic matter by subscribing to a composting service. More than ninety U.S. cities and communities offer municipal food-waste collection (USCC 2015). The city of San Francisco collects more than 500 tons of food waste per day and sends it to a processing facility, which turns it into compost and sells it to local farms (Tyler 2010). This composting service keeps 75 percent of San Francisco's trash out of landfills.

Milwaukee, Wisconsin, is no different and has jumped on the composting bandwagon in recent years. Several start-ups such as Compost Crusader and Purple Cow Organics provide services for food waste pick-up every few weeks – which is where an engineering solution comes into play (Purple Cow Organics 2016). My group plans to design a pod-like composting apparatus that will process the food waste from one hundred Milwaukee households. As the demand from farmers for fresh compost is not enough, the compost produced from our system will likely supply green infrastructure projects in the city. Ideally, the system will be scalable, minimize odors, require minimal physical labor and the lowest possible energy cost by potentially running on solar energy. Several sensors will be appended to the system including temperature, pH, oxygen flow, carbon to nitrogen ratio, electrical conductivity, and moisture content monitors. The product will ideally operate as an independent pod with a targeted retail price of $5,000. A self-sufficient composting system will not only bring awareness to the food wastage epidemic, but also promote the Milwaukee economy.

PROJECT GOAL

We aim to design an economically feasible, aerobic composting system that will accommodate for 100 Milwaukee homes with the potential to be scalable, and will produce a high-quality compost while minimizing odors.

DESIGN SPECIFICATIONS

1. <u>Particle size</u> – 90% of the compost shall pass through a 0.75-inch screen. This ensures optimum surface area for which microorganisms may feed while also creating a homogenous pile which improves insulation (NR 502.12(13)(j) Wis. Adm. Code).
2. <u>Windrow size</u> – Maximum windrow and minimum windrow spacing shall match the capability and requirements of the equipment utilized at the facility (NR 502.12(10)(f) Wis. Adm. Code).
3. <u>Oxygen content</u> – Must not fall below 10% in large pores, which is the threshold for which anaerobic microorganisms can thrive. Pile must be mechanically aerated to ensure proper oxygen flow. Windrow height, structure and porosity shall be designed and maintained to ensure adequate air flow and prevent anaerobic processes (NR 502. 12(10)(d) Wis. Adm. Code).
4. <u>Temperature</u> – A minimum pile temperature of 131 deg. Fahrenheit is to be maintained for three days in order to destroy weed seeds or plant pathogens (NR 502.12(16)(b)3 Wis. Adm. Code).
5. <u>Physical contaminants</u> – The compost shall contain less than 5% combined glass, metal and plastic. Raw materials shall be sorted as needed to ensure that materials are readily compostable (NR 502.12(10)(a) Wis. Adm. Code).

6. Run-off—Run-off from the composting area shall be discharged to a gently sloping vegetated area of sufficient size to prevent erosion and any discrete discharge of liquids or suspended solids (NR 502.12(11)(a) Wis. Adm. Code).
7. Organic matter/ ash content – At least 40% organic matter; less than 60% ash content. Ash shall be disposed of at a solid waste facility licensed by the department to accept the material (NR 502.09(5)(n) Wis. Adm. Code).
8. Carbon to nitrogen ratio – Appropriate sensors will maintain a 10-20:1 C:N ratio for a balanced food source for microorganisms (NR 502.12(12)(b) Wis. Adm. Code).
9. pH – Maintain between 5-8 for optimal performance from compost microorganisms and as an indicator of nutrients in the soil (NR 502.12(13)(f) Wis. Adm. Code).
10. Soluble salts – Electrical conductivity of the composting soil will be below 10 dS m^{-1} as an indicator of available nutrient absorption by crops (NR 502.12(15)(a)2 Wis. Adm. Code).
11. Moisture content – Maintain between 40% and 60% for optimal aerobic composting (nR 502.12(10)(g) Wis. Adm. Code).
12. Maturity – The compost shall be free of compounds such as ammonia and organic acids in concentrations toxic to plant growth (NR 502.12(16)(d), Wis. Adm. Code).
13. Pathogens – The compost shall meet the Class A requirements for pathogens as specified by s. NR 204.07(6)(a), Wis. Adm. Code.
14. Chemical contaminants – The compost shall meet the high-quality pollutant concentrations as specified by s. NR 204.07(5)(c), Wis. Adm. Code.
15. Monitoring, recordkeeping and reporting – Samples of the finished compost shall be collected every 2,000 tons with a minimum of one sample per year (NR 502.12(15)(a)1 Wis. Adm. Code).
16. Physical labor demand – Require minimal physical labor and monitoring
17. Energy demand – Must be powered by solar energy or mostly self-sufficient

PROJECT OUTPUT

The end result of this project will be the creation of a scalable working prototype that includes the necessary sensors and monitors as specified above. This model will be designed in SolidWorks, and appropriate analyses will be conducted before implementation. After the model is tested in the field, the product will ideally be put on the market for sale.

REFERENCES

Journal Articles

Aggelides, S. M., Londra P. A. *2000*. Effects of compost produced from town wastes and sewage sludge on the physical properties of a loamy and a clay soil. *Bioresource Technol., 71*(2000), 253–259.

This study documents and measures the improvement of soil by applying composted city wastes, sewer sludge and sawdust in varying concentrations to loamy and clay soils. Chemical properties of the soil changed, and physical properties improved proportionally to the rate of fertilizer application.

McLatchey, G.P., Reddy, K.R. *1998*. Regulation of organic matter decomposition and nutrient release in a wetland soil. *J. Environ. Qual., 27* (1998), 1268–1274.

This study was conducted to determine the role of redox potential and availability of electron acceptors for microbial processing in wetland areas. The supply of oxygen in wetland soils is relatively low, and alternate sources of electron acceptors must be utilized. This affects microbial population size, enzyme production, and decomposition of organic matter.

Pascual, J.A. et al., *1999*. Comparison of fresh and composted organic waste in their efficacy for the improvement of arid soil quality. *Bioresource Technol., 68*(1999), 244–264.

Fresh and composted wastes were applied to arid soil, and the quality of the soil was analyzed. In both cases, the soil quality improved, but the effects were more evident when fresh waste, as opposed to municipal solid waste and sewer sludge, were applied. The soil in which composted waste was applied showed higher emittance of humic substances and fluvic and humic acids.

Brendecke J.W., Axelson, R.D., Pepper, I.L. *1993*. Soil microbial activity as an indicator of soil fertility: long-term effects of municipal sewage sludge on an arid soil. *Soil Biol. Biochem., 25*(1993), 751–758.

In this four-year study, the efficacy of soil microbial assays for the prediction of effects on land application of municipal waste for long-term soil fertility have been analyzed. The experiment included one unfertilized control plot, and plots with anaerobically digested sewage waste at an ideal rate.

Han, S.K., Shin, H.S., Song, Y.C., Lee, C.Y., Kim, S.H. *2002*. Novel anaerobic process for the recovery of methane and compost from food waste. *Water Science and Technology, 45*(10) 313-319.

The process outlined in this study consists of five leaching beds for hydrolysis, acidification, post-treatment, and an up-flow anaerobic sludge blanket (UASB) reactor for methane recovery. Acidified products from the beds are converted to methane in the UASB reactor. This process showed that it was capable of removing 84.9% of volatile solids (VS) and converting 85.6% of biochemical methane potential (BMP) into methane. The rate of methane gas production was 2.31 $m^3/m^3 \cdot d$.

Sullivan, D. M., A. I. Bary, D. R. Thomas, S. C. Fransen, and C. G. Cogger. *2002*. Food Waste Compost Effects on Fertilizer, Nitrogen Efficiency, Available Nitrogen, and Tall Fescue Yield. *Contribution #11550 from Oregon State Univ. Agric. Exp. Stn. . Soil Sci. Soc. Am. J.* (66) 154-161. doi:10.2136/sssaj2002.1540

The objectives of this study were to determine nitrogen availability and uptake following the application of food compost, analyze the effects of food composting on grass yield, and evaluate the residual effects of compost application on nitrogen fertilizer requirements. The experiment consisted of a slit-plot design with two compost treatments and a no-compost control as main plots, and varying rates of ammonium nitrate application per grass harvest as subplots.

Chikae, M., Ikeda, R., Kerman, K., Morita, Y., Tamiya, E. 2005. Estimation of maturity of compost from food wastes and agro-residues by multiple regression analysis. *School of Materials Science, Japan Advanced Institute of Science and Technology, 65*(10) 341-345.

Germination index (GI) value was used as an indicator of compost maturity for four composting types composed from two kinds of systems and added microorganisms. From the multiple regression analysis of all 159 samples, some parameters were selected to predict GI value. The static aerobic reactor system was found to be the most efficient composting system relative to the dynamic turning pile system.

Sullivan, D.M., Nartea, T.J., Cogger, C.G., Fransen, S.C. *2013.* Nitrogen Availability Seven Years After a High-Rate Food Waste Compost Application. *Compost Science and Utilization 11*(23) 265-275.

This study investigated the long-term effects of food compost application, specifically nitrogen availability, in a 7-year growth trial. Six food waste composts using two composting methods were analyzed. It was found that grass yield and grass nitrogen uptake for the compost treatments was greater than that produced without compost at the same fertilizer nitrogen rate. In addition, soil mineralizable nitrogen tests conducted three and six years after compost application also showed higher nitrogen availability with compost

Chang, K.W., Lee, I.N., Kim, P.J. *2002*. Evaluation of stability of compost prepared with Korean food wastes. *Soil Science and Plant Nutrition 48*(1) 1-8.

The compost maturity of food waste in combination with sawdust, dried paper mill sludge, and decayed wood dust was analyzed using physical, biological and chemical parameters. The carbon to nitrogen ratio, pH, temperature, sodium, and reducing sugar content were measured over time. It was found that the high sodium content in Korean food could be a limiting factor for agricultural utilization.

Chitravadivu, C., Balakrishnan, V., Manikandan, J., Elavazhagan, T., Jayakumar, S. *2009*. Application of Food Waste Compost on Soil Microbial Population in Groundnut Cultivated Soil, India. *Middle-East Journal of Scientific Research 4* (2) 90-93.

This study investigated the effects of food waste composting on microbial populations, soil enzyme activity, and groundnut growth in relation to sodium content and release from compost in soil environment. It has been shown that bacterial, fungal populations and microbial biomass enhances the nutrient availability in soil, improves the insoluble status of elements in the soil, and promotes the production of non-toxic food.

Miscellaneous Publications

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City of Milwaukee. Solid Waste Regulations – Waste Container Regulations. Chapter 79-4. Retrieved from: http://city.milwaukee.gov/ImageLibrary/Groups/ccClerk/Ordinances/Volume-1/CH79.pdf

Patents

Smith-Sebasto, N. (2012). U.S. Patent No. 8,889,407 B2. Newton, New Jersey: U.S.

Nicholas Smith-Sebasto designed an apparatus for the composting of feedstocks into nutrient-rich compost. The design is complete with a means for shredding with a particle size reduction of one cubic inch. The vessel also has a means for introducing air into the main chamber.

Jarrah Ali Abdullah Ali Jaddan Almutairi, A. (2013). U.S. Patent No. 8,603,558 B1. Washington, DC: U.S.

This food waste composting system consists of three stages. In the first housing, food waste is sanitized and then moves to the second stage where the particle size of the food waste is reduced and then dried. In the third stage, the dried food waste is cooled and mixed. The final mixture is then packaged and further processed.

Rune Brandal, Ulsteinvik. (2010). U.S. Patent No. 2010/0281935 A1. Alexandria, VA: U.S.

This system consists of a grinding, dehumidifying, and compost elements. The apparatus also includes means for adding water before the dehumidifier, and means for ensuring that the liquid leaving the dehumidifier has a temperature above 25 degrees Celsius. In addition, a method for producing fertilizer with means of separating fat and liquid fractions is also included.

Self, Tom. (2012). U.S. Patent No. 2012/0252107 A1. Tulsa, OK: U.S.

This apparatus uses a bio-reactor to decompose food waste aerobically and at low temperatures. The reactor includes mixing paddles which aerate and agitate bio-chips which house microorganisms. A water pipe delivers fresh and recycled water and the bio-reactor cycles between water and non-water cycles.

Kerouac, P. (2000). U.S. Patent No. 6,352,855. Hollis, NH: U.S.

The apparatus produces a two-component end product consisting of a bulk organic compost material and a compost-rich, liquid tea. The system includes a shredder that feeds three chambers which combine into a bulk collection container downstream. The systems is also equipped with a motorized drum rotation and means for draining excess fluid from the first chamber, holding a batch volume at an elevated temperature for a period of time.

Hermes, N., Sawada, J.A. (2012). U.S. Patent No. 2012/0137977. Edmonton, CA: U.S.

The food waste composting system comprises a composter that partially composts the waste biomass, an invertebrate culture unit, and delivery subsystem that delivers waste to the culture unit, and a heat exchange subsystem that exchanges heat between the composter and the food culture unit. The system has means for maintaining suitable temperatures for the invertebrate cultures and a process controller to control the amount of heat exchanged.