Internship Final Report

Energy Efficiency and Sustainability

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Background

As global awareness of climate change increases, current energy generation and usage practices face growing scrutiny from governmental institutions and the general public. More pressure is being placed on individual organizations to become more critical of their own energy sources and transition to cleaner technologies. Universities across the nation are among the institutions making this transition. In many cases, universities utilize innovative technologies or lead research and development efforts to improve their reputation while serving as selling points for prospective students. The University of Kentucky (UK) has employed an energy engineer, Britney Thompson, to lead energy efficiency efforts on campus to reduce wasteful energy expenditures. The Office of Sustainability and the Student Sustainability Council have worked in conjunction with Ms. Thompson to develop renewable energy initiatives on campus, including the formation of the energy efficiency and sustainability internship position among the student sustainability internships. My role within this position has been to evaluate the potential energy and cost savings associated with the installation of occupancy sensors, which turn off campus lights while nobody is present. Additionally, my individual project has been to research the technical and economic feasibility of utilizing an anaerobic biodigester on campus to convert food and animal waste into a source of energy.

Efficiency - Occupancy Sensor Installations

Introduction

My work with Britney Thompson has been to evaluate the energy savings on campus lighting through the installation of occupancy sensors. Many bathrooms and hallways remain lit during nights and weekends, even when nobody is present. This results in substantial energy waste and unnecessary expenditures. I have collected and analyzed data to identify target areas that will result in considerable energy savings with quick payback periods. This data justifies the installations and should eventually result in the implementation of these energy-saving sensors.

Methods

To determine the frequency of occupation and lighting usage of a given area, two HOBO data loggers were used. These sensors detect motion and lighting levels, storing data that can show when lights are on while a room is vacant. They were mounted in several restrooms, central hallways, and basement areas throughout the engineering complex for periods of one to two weeks. I recorded the lighting characteristics of each area, such as the bulb wattage and number of bulbs. The data was imported into excel, where I designed a spreadsheet to quantify the duration of unused lighting, and how much energy would be saved in that area if the lights are turned off after a specified period of inactivity.

Figure 1: Data was collected by mounting these HOBO sensors in various areas.

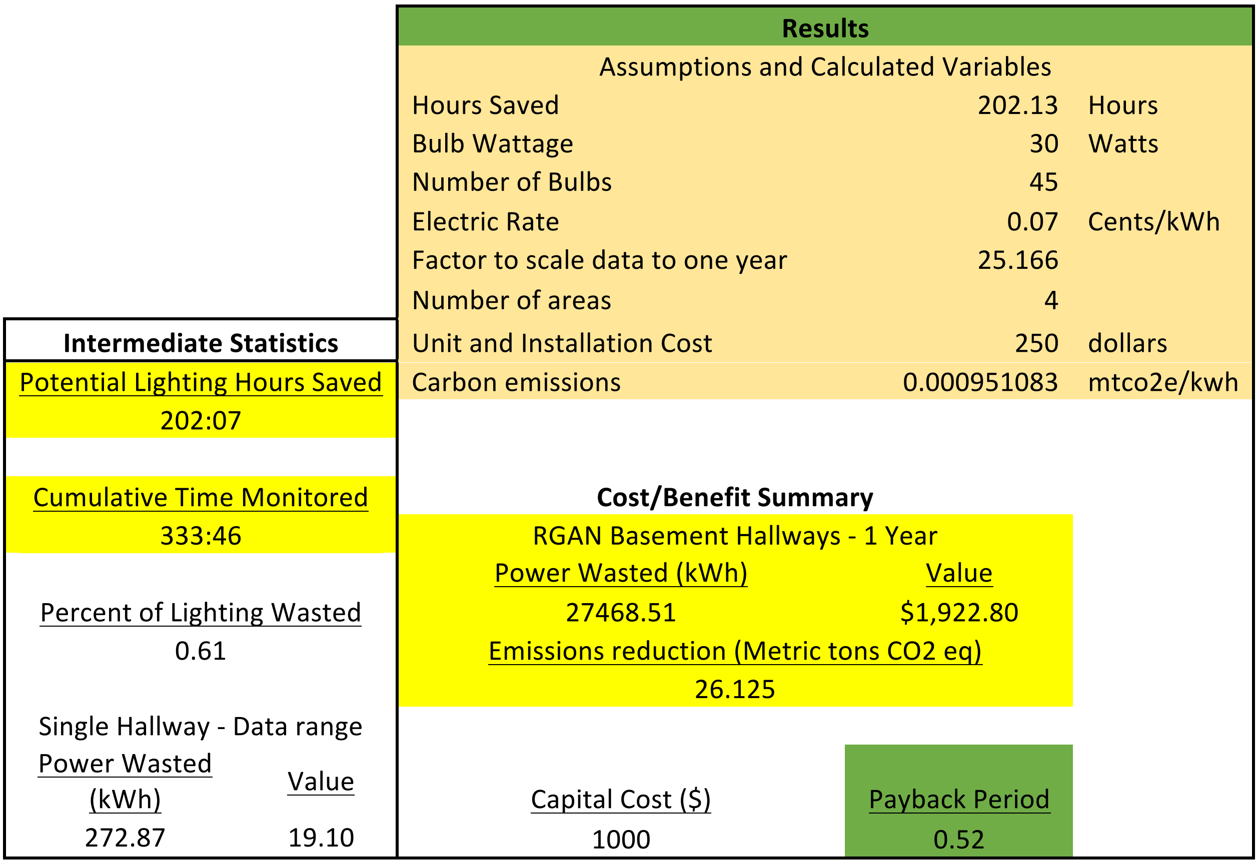
From the energy savings of one data set, the spreadsheet estimates the cost savings and carbon reduction that would occur from installing sensors throughout the whole building.

The user is allowed to specify the number of rooms within the building, lighting characteristics, sensor and installation costs, and the greenhouse gas emissions associated with the particular energy source. This allows the spreadsheet to be easily adjusted to nearly any facility. Our unit and installation costs were provided by Britney Thompson, who based her estimate off of previous sensor purchases, installation times, and labor rates. The carbon dioxide equivalent emissions factor associated with the local energy source, 0.000951 mtCO2e per kWh, was provided by Shane Tedder.

Results

The spreadsheet is a user-friendly tool that calculates energy and cost savings accurately from imported data and a few specified assumptions. Results are displayed in a table that is easy to read. Table 1 shows the results in the exact format created by the spreadsheet.

Table 1: The results for the data from RGAN's basement, as generated by excel.



Results

Assumptions and Calculated Variables		
Hours Saved	202.13	Hours
Bulb Wattage	30	Watts
Number of Bulbs	45	
Electric Rate	0.07	Cents/kWh
Factor to scale data to one year	25.166	
Number of areas	4	
Unit and Installation Cost	250	dollars
Carbon emissions	0.000951083	mtco2e/kwh

Cost/Benefit Summary

RGAN Basement Hallways - 1 Year	
Power Wasted (kWh)	Value
27468.51	$1,922.80
Emissions reduction (Metric tons CO2 eq)	
26.125	

Capital Cost ($)	Payback Period
1000	0.52

Intermediate Statistics

Potential Lighting Hours Saved
202:07

Cumulative Time Monitored
333:46

Percent of Lighting Wasted
0.61

Single Hallway - Data range	
Power Wasted (kWh)	Value
272.87	19.10

Based on the data collected, each of the four locations monitored in the engineering complex would be ideal candidates for occupancy sensor installations. The longest estimated payback period was 1.61 years, which is generally considered to be a sound investment, but the shortest payback is approximately 6 months, located in the hallways of RGAN's basement. An average of 56% of the current lighting usage is wasted energy that could be easily eliminated with occupancy sensors. If sensors were installed in RGAN's bathrooms and hallways, and FPAT's hallways, the university would save approximately 100,000 kWh of energy per year, which translates into approximately $7,000 of annual savings. With an estimated implementation cost of $5,750, this project would have a projected payback period of 10.5 months, which is a desirable timeframe by all standards. Finally, these installations would lower the university's greenhouse gas emissions by 95.5 metric tons of CO_2 equivalent per year. A summary of the results is shown in table 2.

Table 2: A summary of results produced by HOBO data and spreadsheet calculations.

Sample Location Monitored	Percent of Lighting Wasted (%)	Annual Energy Savings for Building (kWh)	Annual Cost Savings for Building ($)	Payback Period (years)	Annual Emissions Reduction (metric tons CO_2 eq)
2nd floor RGAN hallway	38	23,131	1,619	0.62	22.00
2nd floor RGAN bathroom	59	17,738	1,242	1.61	16.87
RGAN basement hallway	61	27,469	1,923	0.52	26.13
5th floor FPAT hallway	66	32,043	2,243	0.78	30.48
Average	56	25,095	1,757	0.88	23.87
Total	**56**	**100,381**	**7,027**	**0.88**	**95.48**

Conclusion

Due to the extremely quick return on an initial investment, it would be appropriate to invest in this project immediately. Savings will accumulate more quickly if this project is implemented soon, and these savings could fund the expansion of the project's scope by installing sensors in other campus locations that will yield similar results. As the scope expands, the university could see substantial savings in energy costs and reduction of greenhouse gas emissions.

Sustainability - Utilizing Anaerobic Digestion

Introduction

The purpose of this study is to examine the technical and economic feasibility of implementing a campus-operated anaerobic digestion system, known as a biodigester, to serve both waste management and energy generation roles. The primary interest is in using campus-generated food waste to produce a methane-based biogas which can be burned to produce electricity. This is best achieved with the co-digestion of food and animal waste, which may come from livestock owned by the University. In addition to being a renewable energy source, the proposed system would also reduce methane emissions typically associated with food waste and livestock.

Anaerobic digestion is the natural process of organic decomposition due to bacteria in an environment without oxygen. Under normal circumstances, this happens when food waste is taken to a landfill. This incurs waste disposal fees, and the methane gas formed generally escapes into the atmosphere. Even larger methane emissions occur due to animal agriculture, where waste collection systems do not capture the methane produced. A biodigester serves as a form of waste management for both of these purposes with several unique benefits. First, the resulting biogas is captured, preventing the release of potent methane gasses. In turn, this biogas may be burned for energy just like natural gas. Since the carbon source is from organic waste instead of a fossil fuel, biogas is a renewable energy source and results in no net carbon emissions. The digester's effluent also serves as an extremely effective fertilizer, with more bioavailable nutrients than animal waste or compost alone. Additionally, the closed system prevents waste from affecting the air or groundwater, leading many farms to utilize biodigesters as a form of pathogen and odor control.

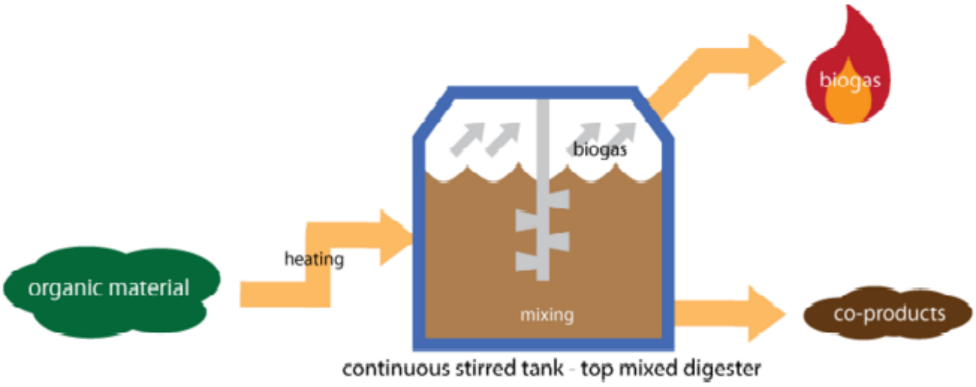


Figure 2: Basic diagram of a biodigester.[1]

This assessment originated as an independent project through the energy internship with the Office of Sustainability. The technical aspects of biodigesters were studied independently through the use of published research, interviews, and information provided by independent and governmental organizations. Faculty from UK provided information about current waste volumes and disposal methods.

Current Operations

Food Waste

Campus food waste is generated primarily by student dining facilities. Without any dedicated food waste disposal, students often dispose of excess food in the general waste bins along with utensils and other non-organic materials. The kitchen generates large quantities of organic waste during food preparation from the remnants of ingredients. Foods that are

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[1] American Biogas Council: http://americanbiogascouncil.org/biogas_wetSystems.asp

expired or damaged are discarded. This includes the portions of many dishes which are unused during operational hours; foods remaining at the end of the day are often discarded.

UK currently disposes of all campus-generated food waste in a landfill, incurring disposal fees and environmental concerns. While some food may be disposed in the wastewater system through the use of a garbage disposal unit, much is also discarded into bins. The food waste discarded in bins accounts for approximately 4 tons of food waste per week, which is taken to a landfill by a private organization in high capacity vehicles. This consequently incurs disposal fees of $27 per ton, totaling $432 per month. Organic waste in landfills also generates a substantial carbon footprint, as anaerobic conditions cause the formation of methane during decomposition. This methane is not captured locally, and is therefore escapes into the atmosphere, where it acts as a potent greenhouse gas that is more than 25 times more potent than carbon dioxide.[2]

Animal Waste

Animal waste has traditionally been the predominant feedstock used in anaerobic digestion due to the high concentration of volatile solids that result in methane production. Therefore, it should be incorporated in the process to increase the potential capacity and efficiency of the biodigester. UK owns a variety of animal units which are distributed on different operating farms. These animals are raised for research purposes, but also necessitate animal waste management systems. The current animal waste management strategies vary depending on the location, type of animal, and number of animals.

The animal units owned by the Department of Animal and Food Sciences in the Woodford County farm are of most interest due to their waste management strategies. This is one of UK's largest groups of animals, therefore generating more waste than the smaller

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[2] https://www3.epa.gov/climatechange/ghgemissions/gases/ch4.html

groups. This farm has a swine unit that currently collects manure in a liquid form, which is stored in above-ground tanks. These tanks were chosen with the intention of possibly retrofitting them to become a biodigester system. They are enclosed, and have the connections that would be necessary for loading and unloading material. Some data from 2011 recorded 647 head of swine owned by UK, and indicated that population tends to remain relatively stable. More data is still required on the housing and waste collection practices with this unit to determine how much of the resulting waste is stored in the tanks, and if it is collected year-round.

There are also beef and sheep units at this location. The sheep flock size is approximately 500 to 600 head, however many of them are not housed inside, meaning that waste is left on the pasture and cannot be utilized. For about six months of the year, 180 ewes and their lambs are housed inside for the lambing seasons. The waste is stored as a solid, and removed from the barn twice per year. The beef unit is comprised of 450 to 550 cattle at any given time, with most of the animals staying on pastures from April to September. When the animals are provided feed at dedicated areas, approximately 300 animals remain completely confined among 3 barns. Sawdust bedding is used within the barn, which becomes mixed with the manure. These solids are removed once per week, and fresh bedding is placed. During this time, the rest of the cattle are fed on an open expanse of concrete that is connected to the pastures. Bedding is not generally used on the concrete, and manure is removed every one or two weeks, however much of the animals' waste falls on the pasture as well, which is not removed. One faculty member indicated that the beef cattle waste is currently stored in a lagoon, which is a technique that may possibly be retrofitted to become a covered-lagoon biodigester.

A critical factor for digester feasibility and sizing is the amount of the feedstock. Therefore the number of animals are used to determine an approximate weight of waste produced. Using head count data from 2011, with standard conversions to animal units of 1000lbs, and waste production data from the Penn State Agronomy Guide, I generated Table 3, which determines the total tonnage of animal waste produced on campus daily. The head of the beef unit corroborated the estimation, saying that for the 300 cattle housed indoors, he would expect approximately 1,188 tons of waste over the six month period. His assumed waste production per animal unit was 55 pounds per 1000 pounds of animal, which is notably lower than the 70 pound estimate provided by Penn State. The theoretical waste production of UK's swine is 6.8 tons per day, which would be 2,482 tons annually if this waste is collected year-round. Although the majority is not recoverable for the purpose of digestion, notice that the total animal waste produced by UK is approximately 60 tons per day, or 21,900 tons annually.

Table 3: Maximum theoretical animal waste production from UK.

	Animals	AU conv. Factor	Animal Units	Manure lb/day	Tons/day	% Dry matter	Tons DW
Dairy Cattle	216	1.3	280.8	100	14.0	12	1.68
Beef Cattle	577	0.9	519.3	70	18.2	9	1.64
Swine	647	0.3	194.1	70	6.8	14.28571	0.97
Goats	47	0.1	4.7	40	0.1	25	0.02
Sheep	594	0.1	59.4	40	1.2	25	0.30
Horses	712	1.2	854.4	45	19.2	20	3.84
Poultry	4112	0.01	41.12	26	0.5	41	0.22
SUM	**6905**		**1953.82**		**60.0**		**8.68**

Proposed System

Project Development

The first aspect of project development would be choosing a suitable site. Based on food and animal waste considerations, an ideal choice would likely be near the farm in Woodford County. While this would necessitate the transportation of food waste from campus to the biodigester’s location, it is much more feasible than transporting animal waste long distances, or locating the digester at the dining facilities. This location would be somewhat remote, removing any possible aesthetic complications, and allowing the effluent to be more easily applied to land as fertilizer. One faculty member indicated that some waste produced by animals at other locations was already being repurposed for use as bedding. However, more research would be needed to determine the waste management practices being utilized at other locations, and the volume of wastes produced. Ultimately, the digester should be located where the highest volume of waste is produced most consistently.

Research and design work would need to be done to develop the best type of biodigester. Depending on the characteristics of the waste and component costs, a biodigeter could be a dry system or a wet system. Most designs tend to focus on mixing a wet slurry to facilitate digestion. In this case, the system would need to have a mechanism for grinding food waste up into a paste or small pieces that can be easily digested. It would also be important to regulate the temperature to facilitate digestion. Depending on the desired retention rate of the materials, digesters can operate on mesophilic or thermophilic conditions. Often, waste heat from the combustion generator can be used in a heat exchanger to keep the biodigester warm. Appropriate insulation may need to be added for operation in winter conditions. The design would likely include pumps for moving material in or out of the biodigester, and there would need to be a system for storing and utilizing the biogas produced. The biogas can be stored in an expandable membrane attached to the tank, or in a pressurized vessel. However, it is ideal to minimize storage and use the biogas as consistently as possible. Typically, it is used in gas-powered generators to produce electricity, similar to natural gas. Alternatively, it is more efficient to use to heat of combustion directly, replacing the direct usage of natural gas for cooking, heating, or lighting.

There are two main ways the project could be developed. A private company could be contracted to perform all necessary design work, which is typical of most biodigesters in the US. This would establish a fairly reliable cost and quality of the project. However, there is a cheaper alternative which could potentially provide even more value. This project could be approached from an educational perspective, with faculty and students leading the design efforts. This would take considerably longer, but could be incorporated into engineering class projects or other extracurricular organizations. Similar to the solar house constructed in 2009, this system could become an interdisciplinary educational opportunity, incorporating students and faculty of agricultural, engineering, and environmental fields to design a system that could generate considerable public interest while having a lasting impact by producing a viable source of electric power and waste management.

Constraints and Assumptions

The most influential factor on project success is a reliable supply of waste to serve as feedstock. The system capacity should be designed to reflect the anticipated size of the waste stream so that operation may be steady and continuous. The biodigester would have to shut down if the waste stream stops, which causes delays in reinitiating anaerobic digestion, and a lack of revenue which adversely impacts the payback period. For a project at UK, a steady waste stream would most ideally be supplied through the swine manure collection system. If the swine provide a baseload feedstock for the system, variable amounts of food waste could be incorporated, displacing some animal waste if necessary. If the manager of the swine unit confirms that a steady waste supply is not available, possibly due to periods of roaming on the pasture, then the timeframe of all waste collection systems from other units should be examined for the possibility of rotating the supply of waste throughout the year.

In the case that a steady waste supply cannot be provided through UK’s present operations, there are a few alternatives to develop the system. The system could be designed to operate on a semi-annual basis, with expectations of reduced efficiency and longer payback periods. More appropriately, however, the university could coordinate with other local agricultural and commercial waste producers to arrange external waste sourcing. With large scale systems, it is possible to enlist a variety of community partners who will adopt the biodigester as their primary form of waste management. In this case, the biodigester could operate as a paid service that would function as a source of project revenue. Industrial food processors, large agricultural operations, and commercial food outlets all have potential to reduce waste management costs by entering a contract with the university, with the additional benefit of an improved public image through sustainable practices.

Another relevant factor to financial viability is that UK can provide the necessary transportation of their own food waste to the biodigester. While this could potentially be done privately, the biodigester should capitalize on multiple sources of revenue while minimizing extraneous costs in order to be profitable. The reduced expenses on waste management and transportation are part of the economic incentive to consider a campus-based waste management system, so as much operation and maintenance labor should be provided internally as possible.

To be economically viable, it is critical that this system receive appropriate permitting to be connected to the electric grid, or otherwise provide power or fuel for campus services. The reduced utility costs are one of the primary drivers for biodigesters, so it would be necessary to demonstrate the potential savings to determine an appropriate project budget. The biodigester's effluent would also need to be examined for possible revenue, as it is typically repurposed as a highly effective fertilizer, or to provide biomass for various other purposes.

Since a biodigester serves as a form of waste management, the current waste management practices have an impact on project cost and feasibility. Some collection and storage techniques are easily converted to be suitable for anaerobic digestion, whereas some farms will have to adjust their practices to facilitate the system. For example, if high amounts of straw bedding are mixed with the waste, it can slow the digestion process. For this reason, it is best to have a waste collection system that minimizes the mixture with other materials. Sometimes the method of physically removing the waste needs to be altered, especially if too much or too little water is used. These practices will need to be observed on a case by case basis to ensure compatibility, but the technical feasibility can certainly be managed with limited modifications to current waste management strategies.

Project Impact

Economic Impact

Although biodigesters may generate regular revenue, they require a significant capital investment, like all electric generation facilities. Estimating these costs are difficult, at they vary significantly with the type of system, current waste management practices, farm size, and other factors. However, some rules of thumb have been developed based on trends of previous project investments. One study determined an average capital cost of $4,500 per kW of installed generation capacity, producing electricity at a levelized cost of $0.062 per kWh.[3] An estimated 18 cubic feet of methane is produced per each animal unit of swine per day, which is equivalent of an energy value of 5.0kWh.[4] Approximately 194 animal units of swine are raised on campus. With an assumed generator efficiency of 35%, and 194 animal units of swine, a biodigester could generate 340kWh daily, which is equivalent to a continuous 14.1kW system. If all beef waste were utilized as well, the total system generation could reach 40.6kW. This would produce 356,000kWh per year, or approximately $25,000 of

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[3] http://www.suscon.org/cowpower/biomethaneSourcebook/Chapter_8.pdf

[4] http://e3a4u.info/energy-technologies/anaerobic-digesters/estimate-potential/

electricity at a grid value of $0.07 per kWh. Using the capital cost estimation, this 40.6kW system would cost $182,700, which would result in a payback period of 7.3 years.

These calculations can only provide very crude estimates of potential project costs, because financial demands can vary dramatically on the resources available, the type of system, and company designing and building the system. The co-digestion of food could improve system performance, yet yield higher costs. While project costs may exceed these estimations, there are a couple of factors that could improve viability. As mentioned within the project development section, internal labor and design resources may have a significant impact on costs. If students and faculty were to approach this project as an extracurricular experience, such as with the solar house, capital costs could be reduced substantially while further justifying the project expenses through the educational value. Another factor that influences project viability is financial assistance provided by incentive programs through grants and loans. The USDA's REAP program offers grants up to $500,000 for qualified projects, which was claimed by a project developed by Ohio State University's Agricultural Research and Development Center.[5][6] However, there are a wide variety of incentives aimed at agricultural, environmental, and industrial efforts which help fund energy development through biomass, which results in numerous options for project financing. By fully exploring both internal and external resources, this project may be pursued without presenting any economic burden.

Finally, the financial aspects of power generation are continuously evolving. Large transitions from coal based power to natural gas and other technologies will affect energy prices in ways that are not entirely predictable. Historically, natural gas prices have not remained stable, which poses certain questions about the future of our energy development.

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[5] http://www.usdairy.com/~/media/usd/public/digesterprojectfundingguide.pdf.ashx

[6] https://www.epa.gov/sites/production/files/2014-12/documents/funding_digestion.pdf

Additionally, if the Clean Power Plan comes into effect, carbon dioxide and other greenhouse gas emissions will become regulated, and have substantial financial implications for the development of electric generation facilities. This could make anaerobic digestion and other renewable technologies considerably more cost competitive due to the potential for rising energy production costs from coal-fired power plants and other fossil fuels.

Environmental Impact

Anaerobic digestion arguably provides more environmental benefits than other sources of renewable energy. Most significantly, agriculture and food waste are dominant contributors to methane emissions, and biodigesters prevent large quantities from being released into the atmosphere. The energy production of a 40.6kW system would consume approximately 10,239 cubic feet of pure methane per day, or 105,827 cubic meters annually. Additionally, biogas is considered a carbon neutral source of energy, because no fossil fuels were burned to release carbon from permanent deposits. Instead, carbon emissions result directly from the decomposition of biomass, in accordance with the traditional carbon cycle. Using the conversion factor of 0.000951 mtCO2e per kWh, this system would prevent 338 metric tons of carbon dioxide emissions annually that would result from traditional fossil fuels.

Additional environmental benefits occur from the waste management aspect of biodigesters. In some areas, numerous complaints of odor can necessitate a form of odor control, and pathogenic contamination of groundwater risks serious illnesses in a large portion of surrounding areas. Because biodigesters are essentially closed systems, they prevent animal waste from affecting the air or groundwater, which in turn is an effective form of pathogen and odor control. In addition to containing odors and pathogens during digestion, the system's effluent has reduced populations of pathogenic organisms and a milder odor.

This effluent is an effective fertilizer, and can replace synthetic products. The nutrients from the effluent are also more bioavailable than traditional compost or the animal waste alone.

Social Implications

There are a variety of social effects that would result from this innovate approach to energy. Perhaps the biggest advantage would be the improvement in the university's image. This would demonstrate UK's commitment to sustainability and promote the idea that this can be feasibly done. The dining facilities would be able to have informational posters explaining how food waste is used to generate electric power for the University, improving public awareness of the concept. Many would appreciate measures to limit emissions from both agriculture and energy usage. Another central benefit that could result from this project is education through experience. If students and faculty worked on the biodigester's design, it would develop invaluable skills, as well as promote a wider interest in sustainable technologies.

Site Visit

Dr. Jian Shi of the Biosystems Engineering department has extensive experience with anaerobic digestion. In addition to providing guidance in my feasibility study, Dr. Shi facilitated a site visit to see an operational biodigester. On March 16, 2016, I visited the biodigester at the Ohio Agricultural Research and Development Center (OARDC) of Ohio State University. The biodigester was designed and operated by Quasar Energy Group, a company which specializes in anaerobic digestion. Quasar's lab manager, Lo Niee Liew, gave me a tour of Quasar's testing facility as well as the biodigester on OARDC's campus. Additionally, Dr. Ge Xumeng showed me the labs and research conducted by himself and the graduate students of OSU.

The facility hosted a 600kW biodigester. This was a demo project to show the co-digestion of food and animal waste, and is the smallest biodigester operated by quasar, which typically focuses on large-scale applications. The tank capacity was 550,000 gallons, and the system handled 20,000 tons of material annually. Lo Niee answered many questions I had about the typical operation strategies, and the conditions that are required to maintain biogas generation. As we toured the plant, she pointed out specific components of the system and how they worked, including how the food was ground into a slurry for the digestion, several heat exchangers, and the large electric generation unit. The tank's ceiling was made of a flexible membrane that rises along with the internal pressure as gasses accumulate.

Figure 3: The co-digestion demo project on OARDC's campus.

Afterwards, Dr. Xumeng described some of his research that could impact the future of anaerobic digestion technologies. One lab was testing the effectiveness of digestion at much higher temperatures than normal. Some research focused on converting the biogas into a liquid biofuel that could be used by vehicles. In addition to the research focused on energy, Dr. Xumeng's students focused on a variety of other bioprocessing elements that could have large benefits to sustainability practices of the future.

Figure 4: Dr. Xumeng described how they were testing various techniques of anaerobic digestion.

Other Notable University Projects

OSU is not the only university taking big strides in innovation and sustainability with biodigesters. The University of Wisconsin Oshkosh is advancing this technology with the first industrial-scale dry biodigester in the Americas.[7] This impressive facility is aggressively improving anaerobic digestion techniques while producing 2,320,000 kWh per year and meeting 15% of the University's electrical needs. The "Feed the Beast" campaign has made the biodigester a popular and educational feature of the university. The University of California, Davis, has implemented the largest biodigester among our nation's college campuses.[8] This system converts 50 tons of waste to 12,000kWh of electricity every day, totaling 5,600,000kWh per year. This system uses technology that a UC Davis professor invented, and prevents nearly 20,000 tons of organic waste from entering landfills each year. The chancellor of UC Davis said, "This project stands as a model public-private partnership and demonstrates what can be achieved when research universities and private industry collaborate to address society's most pressing challenges."

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[7] http://www.biofermenergy.com/references/university-of-wisconsin-oshkosh-biodigester/

[8] https://www.ucdavis.edu/news/biodigester-turns-campus-waste-campus-energy

Conclusion

This is not a project that can be planned overnight. Further investigation is still needed to determine if UK has a suitable environment to complete this project in a cost effective way. However, the technological capability certainly exists, and if the project were determined to be economically viable over the next few years, UK has a lot to gain. In addition to generating clean energy and mitigating waste issues, UK would become a leading figure for commitment to a sustainable future in the United States, and this would certainly earn a positive reputation for our community. Moving forward, this idea certainly merits consideration in any sustainable energy initiatives.

Acknowledgments

This internship has been a wonderful opportunity to learn and explore possibilities of creating an innovative sustainable environment on our campus. Hopefully, this research will be able to contribute to this goal in return. I wanted to thank Shane Tedder and Britney Thompson for overseeing my work, and being very encouraging advisors. Dr. Jian Shi was indispensable in helping me to coordinate a site visit and focus my project's efforts. Lo Niee Liew from Quasar and Dr. Ge Xumeng were very gracious in offering time from their busy schedules to educate me about the process, and show me their facilities. Various faculty from the Animal Science department were very helpful by providing information about current livestock practices. Finally, I wanted to thank the Student Sustainability Council, the Office of Sustainability, and the Tracy Farmer Institute for funding and organizing the program that made this possible.