OPTIMIZING WASTE FLOWS IN THE OSU NETWORK

A Senior Honors Thesis in Industrial and Systems Engineering

by

Cullen Naumoff

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Advisors:

Dr. Joseph Fiksel

Dr. Jerald Brevick

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Abstract

The purpose of this project is to develop a comprehensive model of waste flows at The Ohio State University to enable cost-effective waste reduction. The ultimate goal will be to establish effective solutions that help OSU to move beyond environmental compliance, and take pro-active steps to operate with minimum adverse impact on the environment. This project represents an opportunity to reverse the traditional notion of waste and apply industrial ecology concepts to explore the effectiveness of applying a systems perspective to sustainable modeling.

The model will take the form of EcoFlow™. Developed by researchers at the Center for Resilience at OSU, EcoFlow™ models waste flows in complex networks including multiple inputs, outputs, and decision nodes, to develop a resilient waste management system. In application to OSU, six waste generators were analyzed as input sources that generated five different types of waste. Flow pathways, both currently under operation and hypothetical, provide routes for waste materials to be processed into economically valuable products or energy. Examples of pathways analyzed in the model include recycling, composting, and the capture and utilization of methane gas.

The application of EcoFlow™ utilizes operations research techniques, namely integer programming. This allows for mass balance equations, capacity constraints, and both transportation and operating costs to be integrated into the model to best optimize the objective function. In the case of OSU, the model is programmed to maximize profits within the network. Furthermore, each pathway will be analyzed to show the potential environmental and economic benefits to the waste generator and the waste consumer and how this interacts with the University's triple bottom line, which includes economic, environmental, and social potentials.

Results provide the University with a model of their current waste system and recommend best practices for operation. However most importantly, the OSU EcoFlow™ model offers the University an important tool that systematically optimizes waste flow while simultaneously creating a network that is both economically and ecologically resilient.

Introduction

Modern day socio-economic activities have required massive amounts of material consumption. Material flows at The Ohio State University (OSU) are no exception. The University sends over 2000 tons of material to the landfill on an annual basis. This includes office supplies, food scraps, packaging materials, and electronic wastes. Responsible consumption has become an emerging theme in today's world of over consumption and exhaustion of raw materials.

Although OSU is not in the waste management business, it should act with accountability in managing its waste. This paper focuses on OSU's waste network and quantifies the flow of material within the network. Appendix A shows the interactions of wastes within the system and identifies possible processes to aid in reutilizing the wastes the University generates. The scope of this project was contained to those generating sources that OSU's Facilities Operations and Development (FOD) services currently. Therefore, hospital and athletic waste streams were excluded from the study. In application to OSU, six waste generators were analyzed, including residence halls, academic buildings, dining facilities, recreation facilities, laboratories, and maintenance buildings, as input sources. Solid waste, recyclables, organic waste, and electronic waste serve as the sources of waste in the network. The concept of responsible waste management encourages OSU to redefine what is has traditionally thought of as waste. Excess materials left from the initial utility of a product can be reused/reprocessed to become a feedstock for another operation at OSU or in the market at large. This project highlights the beginnings of a closed-loop system, which allows all feedstocks to be effectively utilized from cradle to cradle.

In effort to optimize the waste flow network, it has been translated into an operations research problem. This allows material flows to be modeled in mass balance equations to ultimately optimize a particular objective function. Appendix B details the entire network as a linear programming model. The main objective in this study due to the data available was to maximize profits, namely through the closed feedback loops within the OSU network. This approach is most closely linked with the University's bottom line approach. However, results that reduce energy consumption and divert material flow to the landfill can be aligned into a triple bottom line approach which takes economic, environmental, and social factors into play. To most effectively reach goals of triple bottom line, this project utilizes the principles of the

Eco-Flow™ model. This allows implementing the linear programming model into software that solves for the optimal solution based on the intended objective function.

Utilizing a triple bottom line approach gives OSU the cutting edge advantage in approaching business and teaching students. These values also align with those set by the Office of Energy Services and Sustainability (ESS), newly implemented at the University. According to the ESS business plan, they intend to promote energy, material, and fiscal accountability while influencing generations of students to act environmentally responsible in their future behaviors. The following project will serve as a catalyzing force to aid in accountable waste management methods at The Ohio State University.

Literature Review

Waste has traditionally been defined as “anything left over or superfluous, as excess material or by-products, not of use for the work in hand.” In a society characterized by “mass-production, mass-consumption, and mass-disposal”[1] waste has become a routine by-product. This by-product is regarded as a non-value added component in production. Traditional “waste” is a result of the “cradle to grave” approach to production that has existed since the Industrial Revolution. This exponential consumption and consequential mass landfilling has become symbolic of success and power.

“The characteristics of waste which make them waste are not inherent, but are determined only relatively in a given social and economic context.”[2] For example, in a household, inputs are disposed after consumption of their original utility, as households do not have the capability to transform the material into other useable forms. Similarly, materials that no longer hold economic value to a generator deem this material invaluable and dispose of it immediately. According to Stephen Levine, “In a real sense, it is this lack of added value that defines industrial waste.”[3]

However, the 21st century has brought pressures in the face of dwindling resources. Citizens worldwide are beginning to rethink their traditional form of consumption. The thought

[1] Moriguchi, Yuichi. "Recycling and Waste Management From the Viewpoint of Material Flow Accounting." Material Cycles Waste Management 1 (1999): 2-9. The Ohio State University, Columbus. Keyword: Material Flow Accounting., pg.2
[2] Same as Above, pg.7
[3] Levine, Stephen H. "Comparing Products and Production in Ecological and Industrial Systems." Journal of Industrial Ecology 7 (2003): 33-42. pg.39

that raw materials are inexhaustible resources is beginning to be reconsidered. In light of these recent trends, "waste" is taking on a brand new definition. Ultimately, "materials are always resources" according to Yuichi Moriguchi. Thus, although the original utility of a material may be exhausted, the remaining material can become another value-added component to another process.

Rethinking waste has sprung from the field of industrial ecology. Industrial ecology has its origins in modeling industrial systems after natural ecosystems. Ecologically speaking, waste does not exist in natural ecosystems. A waste produced by one species becomes nutrients for another. The same process can be modeled in industrial systems. "One of the key themes of industrial ecology is the shift from a linear system where materials, energy , and water are extracted used and discarded, to a closed-loop system where materials, energy, and water are reintroduced into the system after their initial use, for continuous reuse as input material, rather than disposed or emitted as waste."[4]

In effort to accomplish a closed loop system, industrial symbiosis becomes a key implementation method. Industrial symbiosis refers to the development of an "industrial ecosystem." "Industrial symbiosis engages traditionally separate industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water, and/or by-products. The keys to industrial symbiosis are collaboration and the synergistic possibilities offered by geographical proximity."[5] In this scenario, a "waste" generated from one industry can become a feedstock for another process. These wastes can include material by-products to carbon dioxide. In the face of today's growing concern of greenhouse gas output, the ability to reuse these gases in a positive manner yields only beneficial results. This type of collaboration results in a number of economic, environmental, and social benefits. These benefits include the generation of local business opportunities including job creation, reduced energy consumption, reduced material consumption, and stimulating community awareness.

The most well known example of an existing industrial ecopark are the industries of Kalundborg, Denmark. These industries were not initially built with the intention of developing as sustainable ecopark. However, in the first years of operation it became clear that

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[4] Kurup, Biji, William Altham, and Rene Van Berkel. "Triple Bottom Line Accounting Applied for Industrial Symbiosis." ALCAS Conference (2005): 1-14.
[5] Kurup, Biji, William Altham, and Rene Van Berkel. "Triple Bottom Line Accounting Applied for Industrial Symbiosis." ALCAS Conference (2005): 1-14. pg.2

collaborating with one another was of course a sustainable method of operation, but ultimately just made good business sense. This industrial ecosystem includes an oil refinery, a gyproc factory, a pharmaceutical firm, a fish farm, a coal-fired electrical power station and the municipality of Kalundborg. Perhaps they seem as unlikely candidates to be working together, but the relationships have yielded strong results that has led to regulations requiring virtually all discharges by industries be in the form of products that can serve other useful purposes.[6]

Unfortunately, industrial ecosystems tend to be more complex than natural ecosystems because of the flow of money. This has created conflicts that still remain to be resolved in the implementation of industrial ecoparks, and is perhaps that main reason that an ecopark has yet to be built from scratch. Defining a scope and perspective of the industrial network is extremely important. It is not uncommon for the benefits of industrial symbiosis to fall unevenly on participating firms. Often this can create conflict among the network, and thus it is important to clearly define the goals of the symbiosis upon initial collaboration. Furthermore, it is also pivotal to identify "ecological rucksacks" that exist in the system that tend to be overlooked. "Ecological rucksacks refer to the indirect material flows which do not actually enter the economy, but which occur when providing those commodities that do enter the economy. The term implies heavy unseen burdens."[7] It is essential the members of an industrial ecopark address these hidden upstream problems.

The Ohio State University has an opportunity to develop its own industrial ecopark in terms of waste management. Instead of only considering the initial use of various inputs, processes that exist within the ecopark can prolong the life of these feedstocks. The network has the potential to be eco-effective, in that is will benefit the University community both environmentally and economically. As with every industrial symbiosis project, OSU must be able to recognize and balance the benefits associated directly with the University and those that yield beneficial results for the community at large. Ideally, OSU will embrace the roots of industrial ecology and redefine waste as opportunity to maximize product value and performance.

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[6] Peck, Steven. Industrial Ecology: From Theory to Practice. Learned Societies Conference, 1996, Environmental Studies Association of Canada. 13 Dec. 2006.

[7] Moriguchi, Yuichi. "Recycling and Waste Management From the Viewpoint of Material Flow Accounting." Material Cycles Waste Management 1 (1999): 2-9. The Ohio State University, Columbus. Keyword: Material Flow Accounting., pg.2

Methods

Data Collection

In the effort to create a model that most accurately represents the OSU waste flow system, data from a number of resources had to be acquired. In some cases, accurate records had not been kept in which case insights from the supervising role were required. In other scenarios, only partial data existed in which assumptions had to be made to fill in missing links. Methodologies behind data collection for waste generators and processes are described below.

Solid Waste

Solid waste figures were provided by the Solid Waste Management within Facilities, Operation, and Development (FOD) at the University. In 2006, the solid waste division began recording the pounds of solid waste collected at each facility they service including all waste generators included in this study. Solid waste is measured while each building is being serviced by a scale inside the truck. These weights are then recorded and tracked in an online database. This practice began in July 2006 and thus historical records for comparison are not available. At the time of data entry in this study, records had been logged up to February 19, 2007.

Recyclables

Collecting data on recyclable collection at OSU proves to be a challenging endeavor. Currently, the recycling program is headed out of the newly created Office of Energy Services and Sustainability (ESS) at OSU. Despite the current recycling program's existence for 14 years, there exists no data that would offer any insights into the effectiveness of the program. Thus, it is hard to infer what areas utilize recycling bins most often or the materials recycled most. However, in November of 2006 ESS instituted a pilot program to gather data on nine buildings on the effectiveness of co-mingled recyclables. These nine buildings include two maintenance buildings (1100 Kinnear Road and Central Services), six classrooms buildings (Central Classroom, Dreese/Baker, Journalism, Psychology, and Scott Labs), and the Recreation Physical Activity Center. In order to supplement this data, data from Recycle Mania is also included in the study. Recycle Mania is a national contest sponsored by Students for Recycling, a student organization on campus. For the competition, FOD performs volume-to-weight conversions for all recyclables collected from the residence halls and dining facilities. Therefore, recyclable weight data exists for 2006 from January 30 to April 7th.

Both the pilot program and Recycle Mania data exist for approximately three months during the winter season. In effort to gather a year's worth of data, assumptions and calculations were made to create data equivalent to a years worth of data in 2006. See Appendix C for a more detailed explanation on how these numbers were extrapolated.

Recyclables are currently collected in a co-mingled system at OSU. Recyclables include aluminum, steel, glass, plastic, mixed paper, cardboard, and newspaper. Costs and profits incurred due to the collection of recyclables were provided by the OSU Recycling Coordinator.

Organic Waste

There are currently 15 dining facilities located at The Ohio State University. Organic waste at any of these facilities has never been attempted to be tracked. Organic waste in the dining facilities includes food scraps of uneaten food and excess food from the kitchen preparations. Currently, the majority of this food waste is disposed of down the disposal which is then treated through the City of Columbus treatment facilities. Due to resource constraints, performing a small collection experiment exclusively for this study was not feasible. Therefore, the study relies on personal interviews of each facilities operations manager. Each operation manager was interviewed as to how much waste is overproduced behind the line and food left uneaten by students on a daily basis. Most estimated these figures in terms of 30 gallon garage bags; see Appendix D for details on these volume-to-weight conversions. It was evident that facilities that utilize make-to-order operations produce much less food waste than, for example, a buffet line. Daily estimates were then converted into annual food waste production (appendix D.)

Discussions are currently in process at the University to begin to think about recording organic wastes to track compostable material available.

Electronic Waste

Electronic waste at OSU has the opportunity to go in three different directions once collected. The waste can be contracted out to Intechra, a hazardous waste disposal company. Some of the collected waste is disposed of by Shredder, a company which decreases the volume of the electronic waste before sending in to the landfill. The third method is to send this waste to

OSU Surplus where it is refurbished and sold at subsidized prices back to various entities at OSU, including student organizations, academic departments, and individuals. Despite being in existence for more than 10 years, cohesive records of what has entered and left Surplus do not exist. Invoices serve as the only record that an electronic waste product had entered the facility. Due to this, data for this study relies on the insights of the current Surplus manager.

Kurtz Brothers Anaerobic Digestor

Jeff Moore, sales and marketing manager at Kurtz Brothers, was able to provide much of the data in regards to the anaerobic digestor system. The system is still two years out from coming online, so much of the data he provided, including costs and output percentages, are still to some extent theoretical in nature.

Composting at Waterman Farm

A composting pad at Waterman Farm at OSU does not currently exist. Insights into the construction and operation of such a facility was provided by Dr. Fred Michel, a composting specialist operating out of the OARDC OSU facility in Wooster, Ohio. He provided thoughts on the feasibility and also resale values of compost.

Remainder of Data

The remainder of the data, mainly those associated with the new processes in the system, were utilized from the SWACO Eco-Flow™ with the permission of Kieran Sikdar, who built the model. This data is representative of the processes and not necessarily unique to OSU.

Closed Loop System

The foundation of the OSU network is based on a closed loop system. In this system, all wastes that enter the system should be reused at the end of its useful life as a product for another system within the OSU network. In this study, there are two functioning closed loop systems. One of the loops would be considered a market loop. In this such scenario, wastes that OSU produces travel through a variety of processes to eventually re-enter the market as a useable product. OSU then has the opportunity to purchase these products that resulted from their waste stream. The second loop is associated only within the OSU network. In this fashion, wastes that are generated from one area are re-utilized as a feedstock in other processes at OSU. For example, organic waste generated in the dining facilities can be composted at Waterman Farm located on OSU's main campus. Compost generated here can then be used as fertilizer for OSU landscape thus sustaining a closed loop system. Utilizing a closed loop method is essential to rethinking waste in the OSU network.

Operations Research

In order to effectively model the OSU waste network, operations research (OR) techniques were utilized. OR techniques allowed the modeling of system interactions and associated costs simultaneously. Specifically, the model employs linear programming methods allowing the identification of an objective function to maximize earnings in the OSU network. The objective function is optimized with linear constraints that include capacity, mass balance, waste stream percentages, and operating and transportation costs.

Eco-Flow™ Model

Eco-Flow™ is an industrial ecology network model developed by researchers in the Center for Resilience at The Ohio State University. The model utilizes linear programming techniques to model industrial ecology networks in order to maximize profitability and waste reduction. It allows rapid and repeatable calculations of optimal pathways for material utilization. In this manner, various parameters can be changed to parallel the fluctuating nature of industrial systems while still yielding an optimal solution for the network. This model will be applied to the OSU network. Many of the processes recommended in the OSU system are part of the Central Ohio Resource Transformation Center, the original application of Eco-Flow™. These networks represent opportunities to "convert ordinary municipal and industrial solid wastes into streams of marketable commodities, including plastics, metals, fuels, and carbon dioxide."[8] Applying Eco-Flow™ to the OSU network gives the University a tool that will allow them to utilize the optimal waste management methods over a range of varying inputs to best enhance their triple bottom line. The triple bottom line acts as a measure to capture an expanded spectrum of values and criteria to measure OSU's performance in terms of economic, environmental, and social elements.

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[8] Eco-Flow - Industrial Ecology Network Model., Joseph Fiksel, Columbus, OH: Center for Resilience, 2006.

Data

The following section outlines the raw data collected and provides insight into the waste flows in the OSU network. The primary generating sites in this study include residence halls, academic buildings, laboratories, recreation facilities, dining facilities, and maintenance buildings. Currently, most waste generated is treated as mixed solid waste as seen in figure 1. However, one of the goals of this project is to eliminate misconceptions about the non-value added status of materials traditionally thought of as waste.

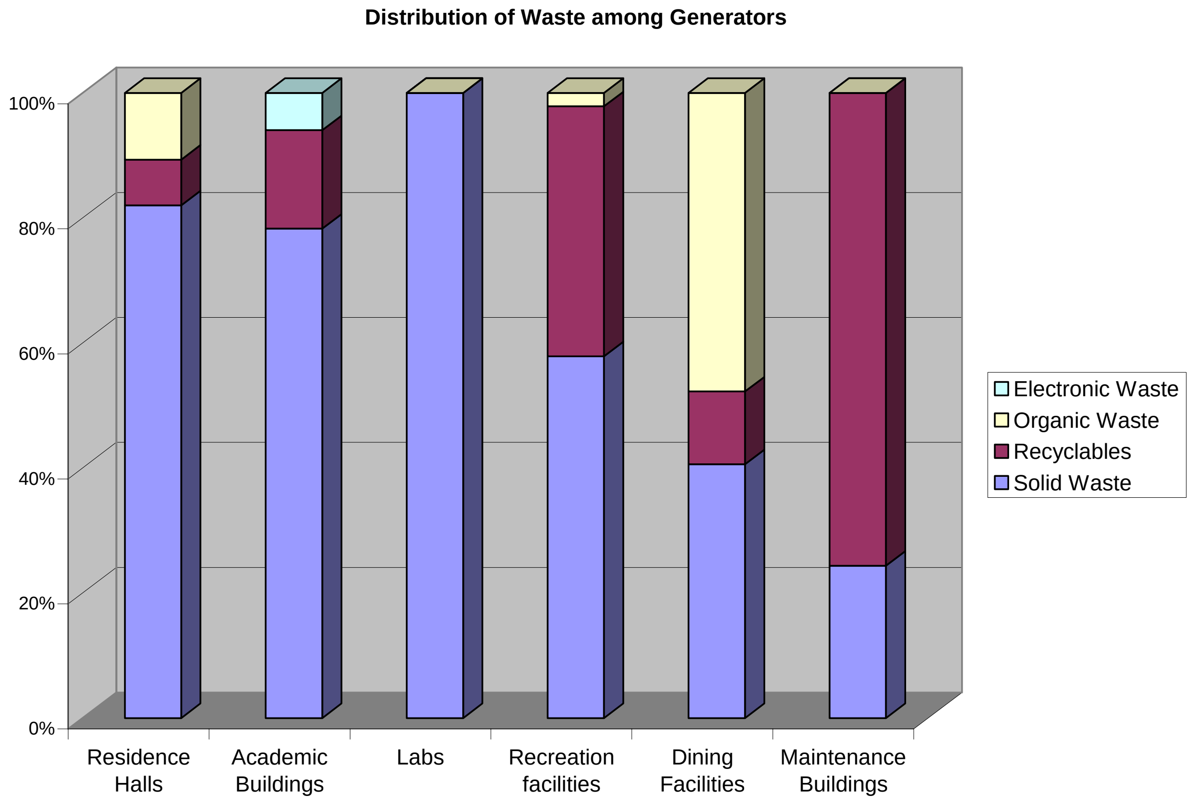

Figure 1: Overall percentage of different waste streams generated from various sources within scope of study.

Solid Waste

As seen in figure 2, most of the waste generated at the University is designated as mixed solid waste. Currently, all food waste is considered as part of this waste, as are many recyclables.

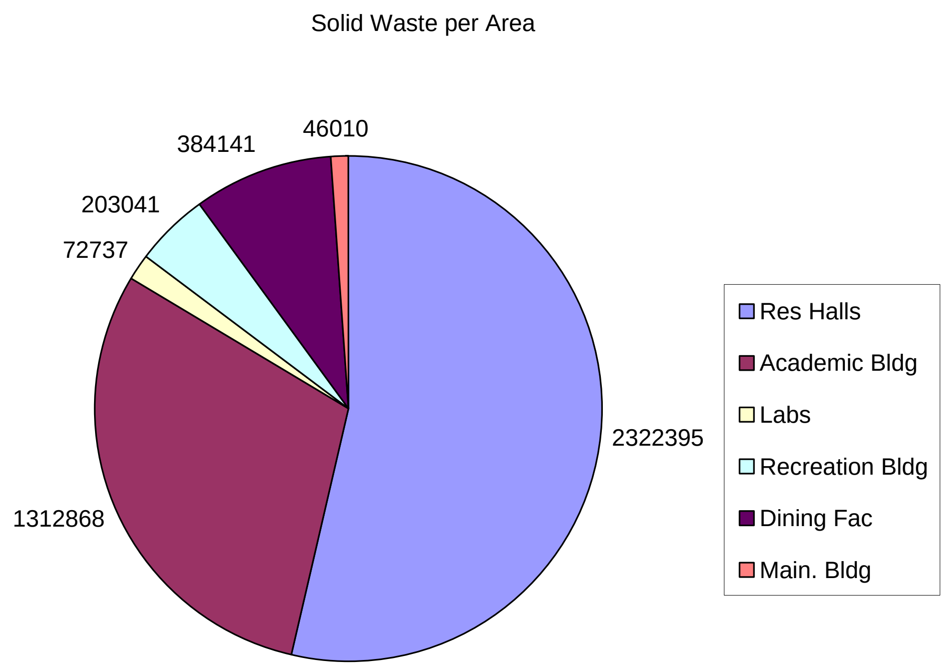

Figure 2: Solid waste generated by each area of campus from July 1, 2006 through February 19, 2007

Figure 2 clearly indicates that residence hall are the biggest producers of solid waste, which is to be expected as they house the largest population of continuous users (approximate 10,000 students) in comparison to all other generator sites. FOD collects solid waste from over 250 sites daily. The solid waste is then taken to Reynolds Avenue Transfer Station for a tipping fee of $48.50/ton where Ohio State considers the waste no longer part of their system. Some of the solid waste, namely compactor or open top boxes, are also hauled by Republic directly to the Solid Waste Authority of Central Ohio's (SWACO) landfill. Fees associated with Republic's service include $34.50 per ton of mixed solid waste, plus a haul charge of $128 and an environmental fee of $15 per load.[9] Currently, OSU Solid Waste Management Staff estimate

[9] A load consists of approximately 5 tons.

80% of the waste is hauled to Reynolds by OSU, and the remaining 20% is taken care of by Republic's services.

Recyclables

Currently, recyclables make up about 19% of the OSU waste steam. In comparison to other benchmark institutions this is a small percentage. Currently, Rutgers University recycles an impressive 57% of their waste stream and University of Michigan follows with a 43% recycling rate.[10] Therefore, it is reasonable to assume with a more systemic recycling program and better recycling awareness among OSU students, the amount of recyclables collected from the waste stream could drastically increase. Presently, the Office of Energy Services and Sustainability is working toward this goal by implementing a co-mingled system through all University buildings. This will create a more convenient environment for students, faculty, and staff alike to put recyclable materials in the recycling flow stream.

Figure 3 indicates that academic buildings are the largest generators of recyclables by weight. Again, this could be assumed because as academic buildings are the largest generators of mixed paper which carries the largest weight as a recyclable. Please see figures 6,7, and 8 in Appendix C to acquire a break down of the type of recyclables generated from each source in the study.

[10] "Results - Grand Champion." Recycle Mania. 15 Apr. 2007. National Recycling Coalition. 7 Mar. 2007 <http://www.recyclemaniacs.org/results-2007.asp?Type=G>.

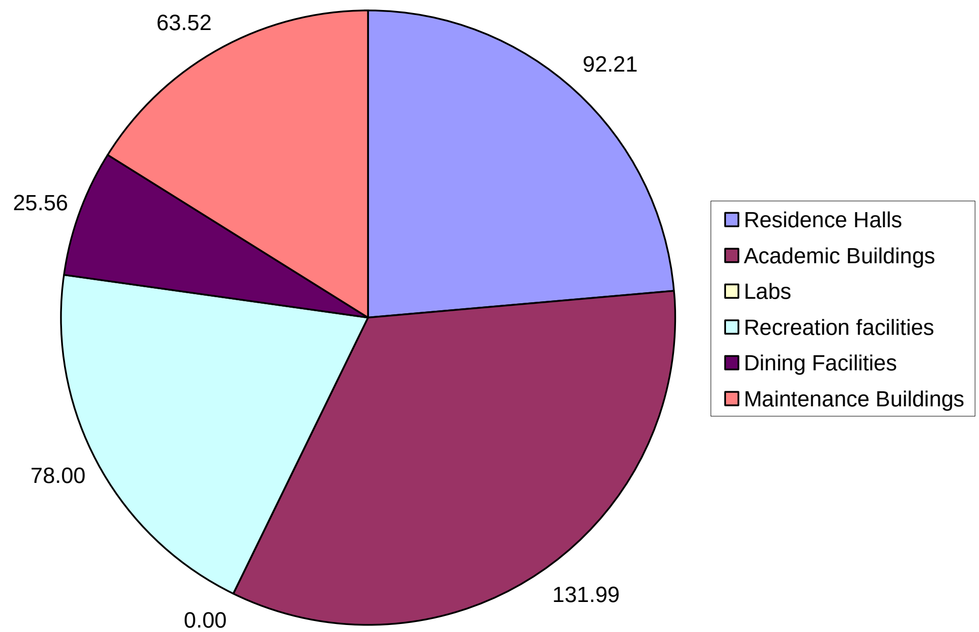

Figure 3: Distribution in tons of recyclables generated from each generating source.

Currently, recycling is not a profitable venture for the University. The solid waste division of FOD dedicates one collection truck to collecting recyclables and each site is collected from every two to three days. Recyclables are then loaded into open top boxes where Rumpke, a local recycling company, collects the boxes for a fee of $10 a ton. FOD collects cardboard separately, which Rumpke will also remove from the OSU network paying OSU $55 per ton for the cardboard. Figure 4 below illustrates the associated costs and savings of the current recycling system considering waste generated by the specified sources.

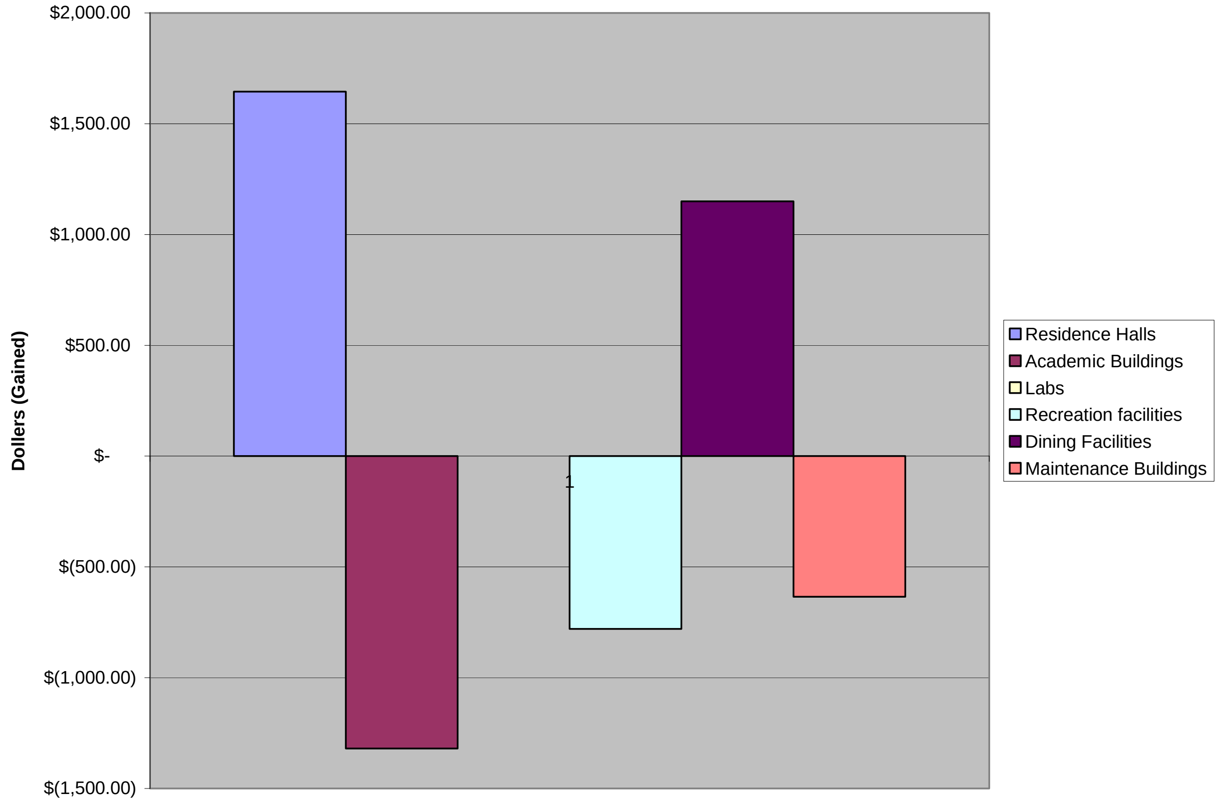

Figure 4: Illustrates the profitability of recycling by generating sources.

When netted, the numbers in Figure 4 yield a $59.45 gain. However, taking annual operating expenses into consideration which requires four salaries and one truck for collection totaling $272,000.00, it becomes clear that recycling has not yet offset its price. Recycling does however, yield a much lower collection cost than mixed solid waste disposal. Increasing the percentage of recycled waste stream will decrease the solid waste going to the landfill and increase the amount of material available to return to the market. In this scenario, the applications of Eco-Flow™ are appropriate as these recycled materials can be further invested in by the market, or even become part of a closed loop system at OSU.

Organic Waste

Organic waste is mainly produced by the dining facilities on campus. Figure 5 outlines the dining facilities on campus and identifies the largest sources of organic waste is being generated from.

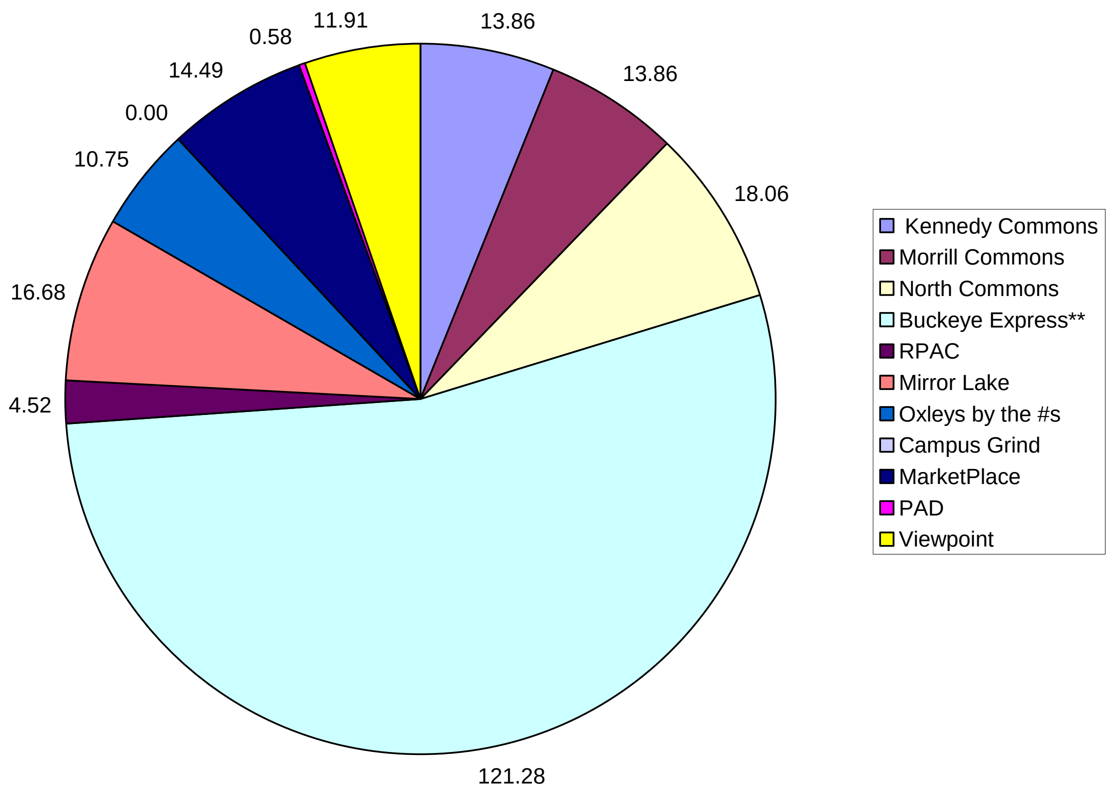

Figure 5: Food waste generated by each of the dining facilities on campus.

Buckeye Express appears to be the largest producers of food waste on campus, yielding about 53.7% of the entirety of the food waste stream. This is mainly due to their method of buffet food production. These facilities experience greater amount of kitchen food scrap and end of the night food waste in comparison to the make-to-order facilities. It should also be noted that recently the Buckeye Express on south campus took the initiative to run an actual food waste only collection period. Therefore, these numbers are most likely the most accurate figures represented and it could be assumed that most of the other dining facilities' food waste production are underestimated. Additional insights into the food waste on campus, include the amount of coffee grinds currently thrown into mixed solid waste stream. The OSU campus alone generates about 2.69 tons of coffee grounds annually. There is a large opportunity that exists within the organic waste stream in which separate collection can yield profitable commodities.

The residence halls also produce a relatively significant amount of food waste. At OSU, no studies have been performed to provide a good estimate as to the amount of food waste discarded in each residence hall. However, other benchmark universities have established dining and residence hall composting programs. They have had success in students collecting food waste in their personal room than taking the food waste to a trash room equipped with a toter to handle food waste. According to data provided by the Purdue University, approximately 13% of residence hall waste is compostable.[11] On account of this figure, an additional 150 tons will be included as part of the OSU organic waste stream for this study's purpose.

Two additional components of food waste that were not incorporated as part of this study include manure (from Waterman Farm) and yard waste. There currently exists a very effective program for yard waste. The University stockpiles grass clippings and un-reusable pallets and brush throughout the year, which are then ground up in the spring for use in University flower beds.

Electronic Waste

All electronic waste being discarded at the University is ideally supposed to travel through OSU Surplus who then decides where the electronic equipment's next destination should be. The majority of the waste is produced by academic departments who are overhauling their technology resources. Once at Surplus, as dictated by resource constraints and quality of materials, management keeps refurbishable items and sends a percentage of the waste to Intechra and Shredder. Intechra operates as a hazardous waste disposal operation that de-manufactures and recycles 100% of retired assets that are non-functional or are too outdated to be remarketed.[12] Unfortunately, any hard data associated with electronic waste could not be determined at the time of this study. Despite multiple attempts in various forms of communication, a connection was never made. Therefore, numbers provided in the study are based on educated guesses by those who work in conjunction with OSU Surplus. Fifty percent of the electronic waste stream is given to Intechra at a cost of $100 per ton. Shredder takes 30%

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[11] Before the Cap and Gown: the Capstone. Purdue University. 2003. 7 May 2007 <http://www.asabe.org/Educate/Feb_2003_R/capstone.html>.
[12] http://www.intechra.com/html/Recycling.html

of the waste stream, leaving 15% for OSU Surplus to refurbish and resell. OSU Surplus takes on the least amount of the waste stream due to space and resource constraints. Realistically speaking, 5% of the e-waste stream will head directly to the landfill.

Kurtz Brothers Anaerobic Digestor

A regional anaerobic digestor is scheduled to begin operation in two years at the Old Trash Burning Plant on Jackson Pike in Columbus, Ohio. Waste from area farms, restaurants, and landscaping businesses will be digested together. OSU has a unique opportunity to partake in this system to gain real benefits from creating profit from food waste. Other universities, that include Ohio University, are interested in starting similar systems on their campuses. However, anaerobic digestors are not cost effective for the relatively small amount of food waste produced by a university campus. However, because the regional model is being developed in the Columbus area, this allows OSU to be a prime candidate to participate in anaerobic digestion.

According to Kurtz Brothers, the products they suspect to output for the digestion process are methane, hydrogen, carbon dioxide, trace amounts of ammonia, and topsoil amendments. The percentages of each product are still theoretical, but from past operations about .5% of the outputs will be gaseous in nature and 10% will be in the form of topsoil amendments. The remainder of the material is lost in evaporation during the process. Kurtz expects to charge customers like OSU $30 per ton for a tipping fee; this does not include transportation for the waste.

There exists much potential for the University to reuse the waste they generated via the outputs from the Kurtz anaerobic digestor. Due to the University providing part of the feedstock that allow the anaerobic digestor to operate, products would be sold back to the University at reduced costs. Hydrogen, for example, could be used to refill the Center for Automotives's hydrogen filling station. Carbon dioxide could be utilized in the OSU greenhouses on Carmack Drive or in various laboratory spaces on campus. Finally, Kurtz Brothers currently has contracts with the University to enhance athletic fields with topsoil amendments. Investments to utilize anaerobic digestion thus have the potential to lead to contracts at reduced costs to sustain the aesthetics and usability of the athletic fields. Further research is necessary to establish useable feedback loops which address purity issues and monetary decisions. See Appendix A for a visual diagram of the feedback loops that exist.

Composting at Waterman Farm

Waterman Farm, located on Carmack Road, has the potential to be an excellent composting site for the University. However, it first must be equipped with composting equipment which include a concrete composting pad and a University employee to manage the operation. Equipment, such as a loader and tractor, are also needed but these could be scheduled into the Farm's operation. Assuming the Waterman composting site could handle fifty percent of the food waste generated on campus, this would require a windrow 100 feet by 12 feet by 4 feet (please see Appendix E for detailed calculations.) Windrow composting is the production of compost by piling organic matter, like food scraps, in long rows, or windrows. This method is suited to producing large volumes of compost, as the routine turning of the organic matter allows continual exposure to oxygen to increase the rate of decomposition.

As indicated by Dr. Fred Michel, associate professor in the Department of Food, Agricultural, and Biological Engineering at The Ohio State University, the composting process typically takes four to eight weeks in the windrow, with an additional four to eight weeks in a storage pile to be complete. The final product yielded is about 20% of the original weight of the feedstock, and remaining 80% is given off in carbon dioxide during the gestation period. Thus, in Ohio State's current operation approximately 22.5 tons of usable compost outputs would be generated on an annual basis.

If a pilot program were to begin at the University, operations would be modeled after composting programs at comparable institutions. Penn State University, for example, has a fully functioning, self-sustaining compost program. It is under their recommendation that one full time employee be hired as a dedicated organic waste collector and utilization a low-loft truck for eight hours a day, five days a week to complete collection. Penn State recommends charging a $55 tipping fee for campus facilities to dump their organic waste in their composting bed, and in Columbus this would be $8 cheaper than the landfill. Furthermore, products generated are sold back to university operations (landscaping, construction sites, turf improvements) at a reduced price. They currently charge $16.82 per ton which is $29.91 cheaper than the market price. At Penn State, this has been adequate to create a self-sustaining program and have additional funds to aid in expanding the program. Table 1 shows how similar figures play out in the OSU system. It is evident that in our current situation the composting program could not self-sustain itself currently, but with proved success the program could grow to a self-sustaining operation. This does not include the $5,509.64[13] investment that would need to be made for the concrete composting pad.

Table 1: Distribution of funds at a potential composting site at Waterman Farms.

Waterman Operations	Employees (1)	Truck (1)	Total Annual Expenditures
	$ 52,000	$ 74,000	$ 126,000
		Dollars Accrued	**Total Annual Grossings**
Composted Collected (tons)	380.68		
Waterman Capacity	190.34	$10,468.56	
Waterman Tipping fee/ton	$55.00		
Compost Produced (tons)	38.07	$1,138.60	
Sold to OSU operations/ton	$29.91		$11,607.16

It should also be noted that adding an organic waste collection route, regardless of it passing through Waterman or the Kurtz Brothers anaerobic digestor, would strain the current collection capacity of FOD. Thus, it would most likely be necessary to hire an additional staff member. This would require an additional investment of $52,000 as an annual salary. Ultimately, the composting program must be well planned for the monetary payback period to occur in a reasonable amount of years. Tina Redman, Recycling Coordinator at OSU, did note that if OSU implemented sealed compactor units in dining facilities the collection frequency could be reduced from 12 times a week to three times per week. In addition to monetary benefits gained from implementing a composting program, it is also important to note the amount of waste diverted from the landfill. Theoretical data shows that possibly over 350 tons of food waste annually could be diverted from the landfill, and this number has potential to grow even larger.

Results

Eco-Flow™ has been formulated with the OSU network data and linear programming formulation. Results yield the optimal flows throughout the system to maximize profits. Table 2 shows the results of current model.

[13] Windrow = 1200 square feet = .0275 acres * $200,000/acre = $5,509.64 investment in concrete pad

Table 2: Optimal waste flows through the OSU network.

Flow Variable	Optimal Flow	Profit or Cost Per Unit Flow	Upper Bound	Lower Bound
MSW to MRF	2170.60	-30	1E+30	27.65
MRF to Landfill	108.53	0	1E+30	553
MRF to Plastics	434.12	0	1E+30	138.25
MRF to Metals	260.47	0	1E+30	230.4167
MRF to Fibers	1302.36	0	1E+30	46.08333
Recycle to Rumpke	432.49	-10	1E+30	71.85
Cardboard to Rumpke	72.22	55	1E+30	118.1
Organics to Kurtz Digestor	57.00	-30	1E+30	35.1
Organics to Waterman	67.50	-55	1E+30	10.927
Organics to Landfill	255.98	-63.1	10.927	1E+30
Ewaste to OSU Surplus	80.42	-20	1E+30	1080
Ewaste to Intechra	187.64	-100	1080	1E+30
Ewaste to Shredder	80.42	-75	1E+30	1E+30
Rumpke to Metals	43.25	0	1E+30	718.5
Rumpke to Plastics	86.50	0	1E+30	359.25
Rumpke to Paper	216.24	0	1E+30	143.7
Rumpke to Cardboard	68.61	0	1E+30	124.3158
Rumpke to Landfill	25.24	0	1E+30	1437
Kurtz AD to AD Clean Gas	0.28	0	1E+30	7264.073
Kurtz AD to Landfill	0.57	0	1E+30	3510
Kurtz AD to Compost	5.70	0	1E+30	248.8
AD Clean Gas to AD Gas Clean	0.28	0	1E+30	0
AD Gas Clean to Methan	0.19	0	1E+30	0
Landfill to FirmGreen	4000.00	0	1E+30	1E+30
FirmGreen to CO2	2000.00	0	0	1E+30
FirmGreen to H2	2000.00	0	0	1E+30
Waterman to Landfill	3.38	-63.1	1E+30	218.54
Waterman to Compost	13.50	0	1E+30	54.635
Waterman to Gas	50.63	0	1E+30	14.56933
OSU Surplus to Refurbish Electron.	80.42	0	1E+30	1080
Shredder to Landfill	80.42	0	1E+30	1E+30
Ewaste to Landfill	26.81	-63.1	1E+30	0
CO2 to Methane	2000.00	0	0	1E+30
CH4 Product to Methane	2000.00	0	0	0
Refurbish. To OSU Academics	80.42	1000	1E+30	1080
OSU Topsoil Amendments	5.70	20	1E+30	351
Compost to OSU Landscape	13.50	29.91	1E+30	19.91
Paper to OSU Purchasing	108.12	75	1E+30	287.4

Not every arc within the network was utilized, as they were not part of the optimal solution. The optimal flow is given in tons and some are constrained by capacity conditions. Profit or cost per unit flow are the prices that were entered into the original formulation. Finally, the lower and upper bounds represent the range of flow amounts that the given solution will remain optimal. As noted in table 2, the majority of the flows have an infinite upper bound flexibility.

Furthermore, table 3 contains the network flows constrained by the capacity constraints. Processes that are filled to capacity yield insights into the most desirable processes for the OSU network. The shadow price represents the unit price or cost associated with increasing constraint value, as long as the constraint value remains within the bound limits.

Table 3: Illustrates processes constrained by capacity

Constraint Identifier	Optimal Flow	Shadow Price	Constraint Value	Upper Bound	Lower Bound
Novelis Capacity	0	0.00	3500000	1.E+30	3,500,000
Rumpke Capacity	432	0.00	250000	1.E+30	249,568
Kurtz Digestor Capacity	57	35.10	57	256	57
Waterman Pad Capacity	68	10.93	67.5	256	68
OSU Surplus	80	0.00	80.42	1.E+30	0

Finally, the following table (table 4) highlights the main findings that result from the optimal solution.

Table 4: Overall summary of results from the OSU Eco-Flow™ model

OSU NETWORK PERFORMANCE SUMMARY FROM ECO-FLOW™			
Waste Generated	5537.6	Cost to disposal for OSU	-$119,326
Waste Landfilled	500.9	Savings within system from closed loop interactions	$93,016
Waste Diverted	5036.7	Future annual waste costs OSU would pay[14]	$26,310
Landfill Diversion Rate	91.0%	Savings in Waste Disposal[15]	$290,749

[14] Cost to disposal ($119,326) – Savings in network ($93,016) = $26, 310 annually
[15] Current disposal costs incurred by OSU ($317,059) – Future disposal costs (26,310) = $290,749 annually

Discussion

The Eco-Flow™ model is a very powerful tool that allows users to take a systems perspective of a particular network. In this particular study, only the surface potential of the model was scratched. The model created for this study was mainly based on the economics of the OSU network, but with appropriate data, emissions and energy can also become an integral part of the model. This would allow OSU to not only maximize monetary returns in the system, but also minimize emissions and energy consumption. This could be essential in OSU taking the lead in becoming an environmentally and economically sustainable campus and community.

Furthermore, there are two levels that exist in the model. The first level is rethinking the notion of waste in a general sense. In the OSU network, no longer should we assume that wastes produced on campus are non-value added items; but instead, we can transform this waste into a product or feedstock to be re-utilized back in the market. As Andrew Mangan of the US Business Council for Sustainable Development notes, "No longer should we focus on zero-waste, but 100% product." In this sense, OSU would be participating in a regional venture to benefit the greater community in sending less material to the landfill and reducing consumption of raw material.

The second level is the closed loop that exists only in the OSU system. These closed loops require every waste generated by OSU to be utilized as a product or feedstock directly back at OSU. This is the ideal scenario. This allows OSU to use all resources cost effectively and eco-effectively. Closed loops within the network create "highly industrious, astonishingly productive and creative"[16] usability of materials. The best example currently within the OSU system is the potential that organic waste provides. Collecting over 200 tons annually from the dining facilities will yield in the production of hydrogen and carbon dioxide gases that could serve as the replenishment source for various labs on campus. Compost generated could provide high quality fertilizer to OSU operations involved with landscaping. Furthermore, anaerobic digestion yields a solid topsoil amendment product used on the many athletic fields on campus. In this example, OSU purchases food which the campus community utilizes first. Afterwards, scraps are then recycled in a manner that allows these original purchases to be continue to be used in a beneficial way.

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[16] Chertow, Marian R. "Industrial Symbiosis: Literature and Taxonomy." Annual Review Energy Environment 25 (2000): 314-334. ARJournals. The Ohio State University, Columbus. 14 Apr. 2007. Keyword: industrial symbiosis.

The second feedback loop was the focus of this study and was the primary driver in optimizing the OSU network. It is obvious that the network has not been perfected, as the overall net profits were a negative value. However, it should be noted that if all these wastes had instead been sent to the landfill it would have cost OSU $317,059. Therefore, even with an imperfect system the University saves just under $300,000 in waste management costs. OSU closed loop savings for many of the potential feedback arcs have not been included in this study due to their theoretical nature. These additional feedbacks will therefore yield an even greater positive value within the system. Furthermore, with the existing network over 5000 tons of waste of diverted from the landfill on an annual basis. This is nearly ten times the amount of waste that is currently diverted from the landfill. This result is an essential enhancement of OSU's triple bottom line.

Also, it is clear that processes that return profits back to the OSU system are favorable to the optimal solution. This is best seen in the capacity results (table 3.) Processes that include Kurtz Brother's anaerobic digestor, composting at Waterman farm, and refurbishing electronics at OSU Surplus are all operating at full capacity. Capacity constraints are defined by lack of resources and space available at the University to have a fully functioning program. However, it is evident the savings they generate offer positive benefits to the OSU network and are perhaps worth investing in for the future to increase capacity.

It should be noted an ideal feedback loop does exist for all wastes generated at OSU. Ultimately, OSU is not in the waste management business and thus it is not in their interest to establish, for example, a recycling processing facility on campus. This however does create issues in closing all OSU loops. Recyclables generated create the largest problem in this realm. OSU does not benefit from the direct utility of recycled sheet metal or plastic from a mill. In this scenario, a general feedback to the economic market makes more sense and simultaneously continues to enhance OSU's triple bottom line.

Recommendations

Further data would enhance the model to show the balance of economic and environmental benefits to OSU. For example, straight economics show it is more cost-effective for OSU to purchase virgin paper in comparison to post-consumer recycled content material. However, a systems perspective shows that utilizing the feedbacks within the system illustrates that purchasing post-consumer recycled content paper is a more desirable decision. This would be most effectively shown with energy and emissions data included as part of the current model as was discussed in the Discussion section. Energy data will require intense inquiry as energy consumed for each process as well as alternative measures (eg. producing paper from virgin materials) must be integrated into the model. Emissions from these processes as well as transportation could also yield key insights into the OSU network.

Additionally, feedback loops within the OSU network should continue to be analyzed. For example, utilizing methane gas and other GHGs on campus is a real possibility. However, logistics and prices must be investigated further before they can become an integral part of the network. The study has proposed several of these theoretical feedback loops including providing hydrogen to the CAR filling station and methane to perhaps generate electricity on campus. However, additional loops must continue to be explored. Academic departments, students affairs, and the purchasing department should also be questioned thoroughly as to evaluate all needs for various resources across campus. The purchasing department, specifically, has a unique potential to be an integral part of resourcefully creating additional OSU closed loops. Essentially they control all inputs into the system which can greatly influence the outputs. Smart decisions by the purchasing department can lead to an even more effective OSU waste management network.

Furthermore, in this study a more comprehensive operations research solution would have integrated the OSU feedback loops and general market feedback loops. This would most effectively illustrate 1) the benefits to OSU, economically and ecologically, and 2) the regional benefits created by OSU becoming more industrious with their waste.

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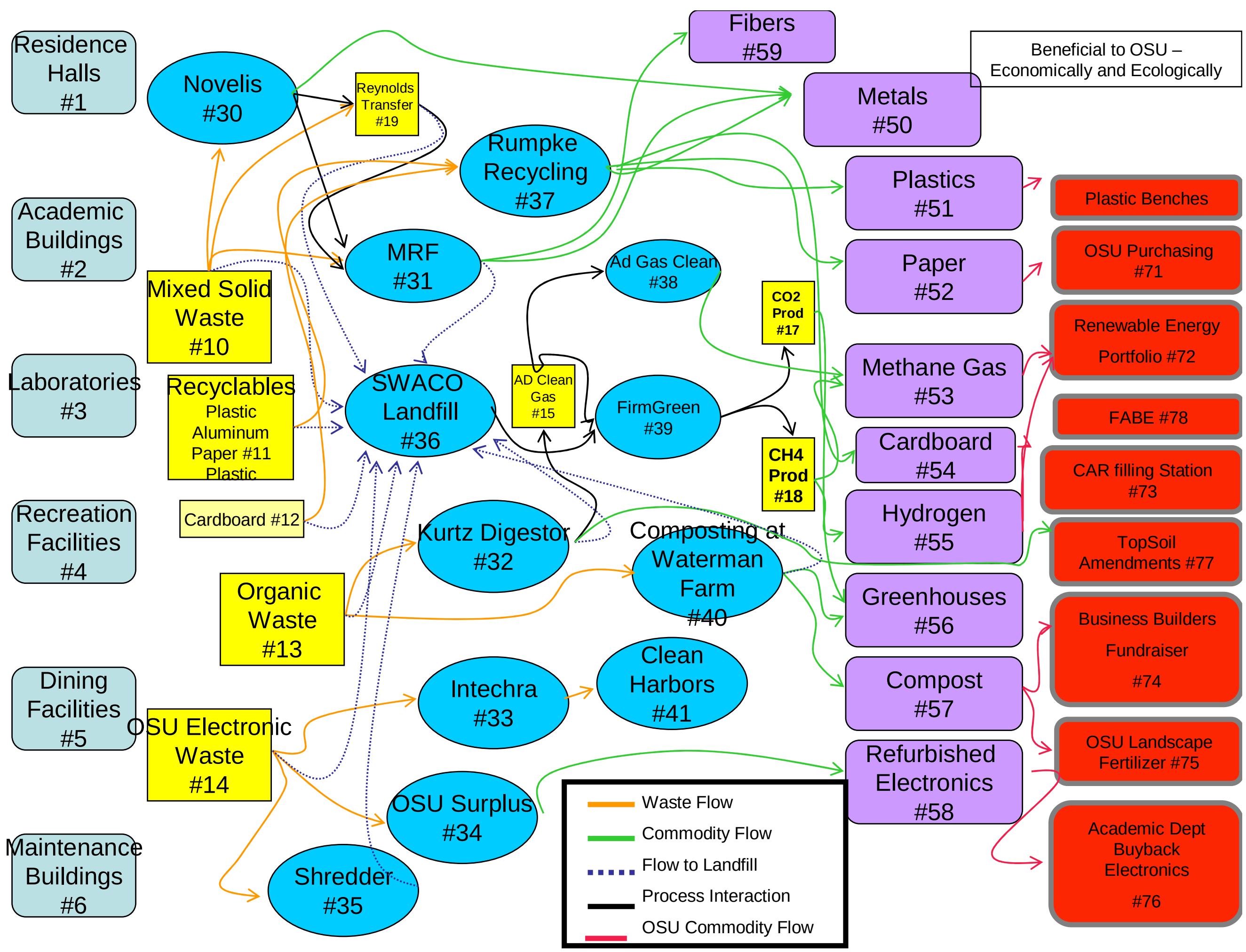
Appendix A

OSU Waste Network



Appendix B

Linear Programming Model

Objective Function

Maximize Profits	-63.10x1036 – 57.65x1019 – 85x1030 -30x1031	(MSW)
	-10x1137 – 63.10x1136 – 63.10x1236 + 55x1237	(Recyclables +CB)
	-30x1332 – 55x1340 – 63.10x1336	(Organic Waste)
	-100x1433 – 20x1434 – 75x1435 -63.10x1436	(Electronic Waste)
	+10x5774 + 29.91x5775 + 20x3277	(Waterman + Kurtz)
	+1000x5876	(Surplus Profits)
	+100x5271	(Savings in paper purchasing)

Decision Nodes

Mixed Solid Waste #10

x0110 + x0210 + x0310 + x0410 + x0510 + x0610 = x1030 + x1031 + x1036 + x1019 (mass balance)

$-\frac{(\$128+\$15)x1036}{5\text{ tons}} - \$34.50x1036$ (SWACO landfill + transportation cost)

$\$48.50x1019 + \$45.75\frac{(x1019)}{5\text{ tons}}$ (Tipping Fee + Transportation to Reynolds)

Recyclables #11

x0111 + x0211 +x0411 + x0511 +x0611 = x1137 + x1136 (mass balance)

+$55 (x1237) (Company pays OSU for CB)

Cardboard #12

x0112 + x0512 = x1237 + x1236 (mass balance)

+$55x1237 (Company pays OSU for CB)

Organic Waste #13

x0113 + x0513 + x0413 = x1332 + x1340 + x1336 (mass balance)

+$40(.2(x1340)) (profit per ton of compost at Waterman)

-$30x1332 (organic waste to Kurtz Brothers)

-$63x1336 (organic waste to landfill)

Electronic Waste #14

x0214 = x1435 + x1434 + x1433 + x1436 (mass balance)

.5x0214 = x1433 (Ewaste to Intechra)

.3x0214 = x1435 (Ewaste to Shredder)

.15x0214 = x1434 (Ewaste to Surplus)

.05x0214 = x1436 (Ewaste to Landfill)

Clean AD Gas #15

x3215 = x1538 + x1539 (mass balance)

FirmGreen Gas to Products #16

x1539 = x3917 + x3918 (mass balance)

CH4 Production #18

x3918 = x1855 + x1853 (mass balance)

CO2 Production #17

x3917 = x1756 (mass balance)

Reynolds Transfer #19

x1019 + x3019 = x1936 + x1931 (mass balance)

-$48.50x1019 - $45.75(x1019/5) (tipping plus transport fee to OSU)

Process Nodes

Novelis #30

x1030 = x3031 + x3050 + x3019 (mass balance)

.12x1030 = x3050 (Metals Output)

.88x1030 = x3019 (Waste Output)

x1030 < 350,000 (*Capacity*)

-$85x1030 (OSU charged per ton)

MRF (WastAway) #31

.97(x1031 + x3031 + x1931) = x3136 + x3159 + x3150 + x3151 (mass balance)

.12(x1031 + x3031 + x1931) = x3150 (Metals in System)

.2(x1031 + x3031 + x1931) = x3151 (Plastics Output)

.6(x1031 + x3031 + x1931) = x3159 (Fibers output)

.05(x1031 + x3031 + x1931) = x3136 (to landfill)

-$30x1031 (Tipping fee)

Intechra #33

x1433 = x3341 (Intechra to Clean Harbors)

-100x1433 (Cost to OSU for Intechra's Service)

OSU Surplus #34

x1434 = x3458 (Reburbished Ewaste)

x3458 = x5876 (Bought back by OSU depts.)

$1000x5876 (Profits made)

x1434 <80.42 (Surplus capacity)

<u>Shredder #35</u>

x1435 = x3536 (Shreds to Landfill)

-$75x3536 (Cost to OSU for Shredder’s Services)

<u>Recycling #37</u>

x1137 + x1237 = x3750 + x3751 + x3752 + x3754 + x3736 + (mass balance)

.5x1137 = x3752 (paper recycling)

.2x1137 = x3751 (plastic recycling)

.25x1137 = x3750 (metal recycling)

.05x1137 + .05x1237 = x3736 (unrecyclables to landfill)

.5x3752 = x5271 (recycled content to OSU paper)

x1137 + x1237 *<250,000* *(capacity)*

-$10x1137 (processing cost)

+$55x1237 (cardboard profit)

<u>Kurtz Digestor #32</u>

.114832x1332 = x3215 + x3236 + x3257 (mass balance)

.004832x1332 = x3215 (AD Gas Separation)

.01x1332 = x3236 (AD Waste to Landfill)

.1x1332 = x3277 (AD Solids to Topsoil)

x1332 < 57 (Capacity: 15% of organic waste)

-$30x1332 (Processing Cost for OSU)

$20x3277 (Savings in topsoil amendments)

Composting at Waterman #40

x1340 = x4056 + x4057 + x4036 (mass balance)

.05x1340 = x4036 (contaminated waste to landfill)

.2x1340 = x4057 (actual compost)

.75x1340 = x4056 (CO2 Products)

x4057 = x5774 + x5775 (OSU compost to products)

+$10x4057 (cut of Business Builders fund (25%))

+$29.91x5775 (savings on fertilizer)

x1340 < 67.5 (capacity due to pad)

FirmGreen #39

x3639 + x1539 = x3917 + x3918 (mass balance)

.5(x3639 + x1539) = x3917 (CO2 Production)

.5(x3639 + x1539) = x3918 (H2 Production)

-$75x3639 – $125x1539 (Costs incurred by OSU)

Kurtz AD Gas Clean #38

.7x1538 = x3853 (mass balance)

Appendix C

Recycling

Residence Halls numbers based on:

Total Residence Halls = 35

Annual numbers based on a three month period (January – March, Winter Quarter 2006)

Average tons recycled in period: 34.58 tons

Tons of recyclables annually: 3 quarters x 34.58 tons = **103.74**

Please note these numbers are slightly skewed as they are based only on collection data during winter quarter.

Dining Facilities numbers based on:

Total Dining facilities with recorded data: 3

Annual numbers based on a three month period (January – March, Winter Quarter 2006)

Average tons recycled in period: 5.75 tons

Tons of recyclables annually: (5.75 tons/3) * 5 dining facilities who collect recyclables *3 quarters in a year = **55.1**

Academic Building numbers based on:

Total Academic Buildings with recorded data: 5

Annual numbers based on September 2005 – May 2006

Average tons recycled in period: 6.47 tons

Tons of recyclables annually: (6.47 tons/5 buildings) *120 academic buildings located on campus = **131.99**

Recreation Facilities numbers based on:

Total Academic Buildings with recorded data: 1 (RPAC)

Annual numbers based on pilot program data (November 2006 – February 2007)

Average tons recycled in period: 1.95

Tons of recyclables annually: (1.95 tons * 16 collection recreation facilities)/4 months * 9 months of operation = **70.2**

Maintenance Building numbers based on:

Total Maintenance with recorded data: 2

Annual numbers based on pilot program data (November 2006 – February 2007)

Average tons recycled in period: 3.97

Tons of recyclables annually: ((3.97 tons in 2 buildings) * 8 (for 16 facilities))/4 months * 9 months of operation = **71.46**

Table 5: Illustration of recycling extrapolated data

Type of Waste	Inputs	Tons	Cardboard (tons)	Multiplying factor	Adjusted Tons	Adjusted Cardboard
Recyclables	Residence Halls	34.58	17.5	3	103.74	52.50
	Academic Buildings	6.47		20.4	131.99	
	Labs	0.00	0	0	0.00	
	Recreation facilities	1.95		4	70.20	
	Dining Facilities	5.75	6.648	9.583333333	55.10	28.75
	Maintenance Buildings	3.97		2	71.46	
Total tons annually:					**432.49**	**81.25**

Types of Recyclables from each facility:

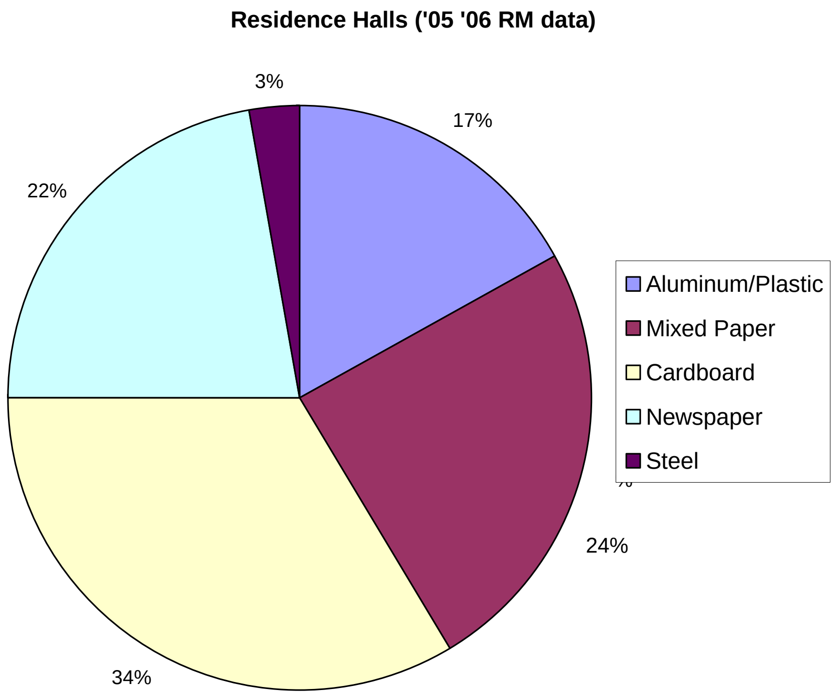


Figure 6: Distribution of the type of recyclables generated from the residence halls.

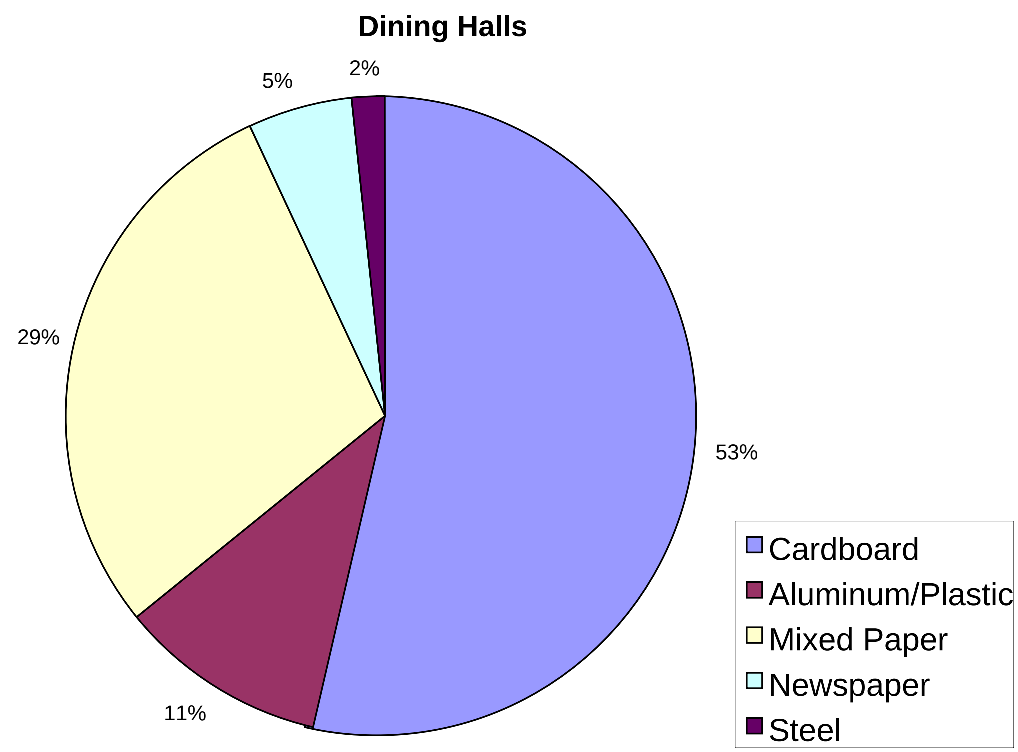


Figure 7: Distribution of the type of recyclables generated from the dining halls.

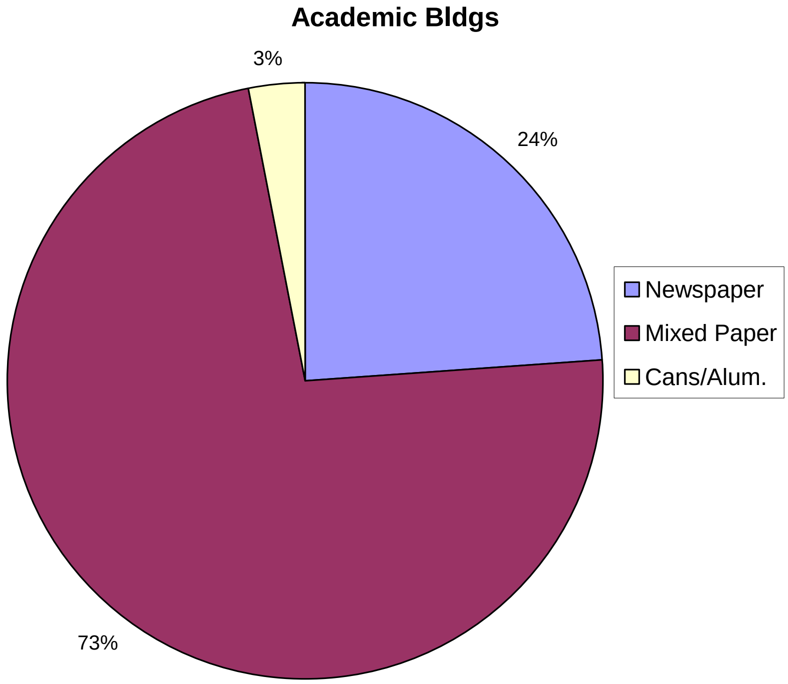


Figure 8: Distribution of the type of recyclables generated from the academic buildings.

Appendix D

Dining Facilities

Assumed days of operation for each facility:

Commons (Kennedy and Morrill):
3 quarters * 11 weeks = 33 weeks of operation * $\frac{7 \text{ days}}{1 \text{ week}}$ = 231 days .

North: 3 quarters * 11 weeks +10 weeks of summer = 33 weeks of operation * $\frac{7 \text{ days}}{1 \text{ week}}$
= 301 days

Mirror Lake Café:
3 quarters * 11 weeks = 33 weeks of operation * $\frac{7 \text{ days}}{1 \text{ week}}$ = 231 days .

Oxley's by the Numbers:
3 quarters * 11 weeks +10 weeks of summer = 33 weeks of operation * <u>5 days</u> = 215 days
1 week

RPAC:
3 quarters * 11 weeks +10 weeks of summer = 33 weeks of operation * <u>7 days</u> = 301 days
1 week

Campus Grind:
3 quarters * 11 weeks = 33 weeks of operation * <u>5 days</u> = 165 days .
1 week

Marketplace:
3 quarters * 11 weeks +10 weeks of summer = 33 weeks of operation * <u>7 days</u> = 301 days
1 week

Viewpoint Bistro:
3 quarters * 11 weeks = 33 weeks of operation * <u>5 days</u> = 165 days .
1 week

Pizza at the Drake (PAD):
3 quarters * 11 weeks = 33 weeks of operation * <u>7 days</u> = 231 days .
1 week

Dining Facility	lbs/day	gal/day	days/yr	ft3/gal	lb/ft3*	ton/lbs	tons/yr
Kennedy Commons	120		231	0.133681	18	0.0005	**13.86**
Morrill Commons	120		231			0.0005	**13.86**
North Commons	120		301			0.0005	**18.06**
Buckeye Express**	350		231			0.0005	**121.28**
RPAC	30		301			0.0005	**4.52**
Mirror Lake		60	231	0.133681	18	0.0005	**16.68**
Oxleys by the #s	100		215	0.133681	18	0.0005	**10.75**
Campus Grind			165	0.133681	18	0.0005	**0.00**
MarketPlace		40	301	0.133681	18	0.0005	**14.49**
PAD	5		231			0.0005	**0.58**
Viewpoint		60	165	0.133681	18	0.0005	**11.91**
Total Annual Food Waste:							***225.97***

*Assuming bread conversion from "Standard Volume-to-Weight Conversion Factors"

**There are 3 Buckeye Expresses on campus.

***According to http://www.nmenv.state.nm.us/SWB/doc/Conversiontable.doc

Appendix E

Waterman Farms

Compost pad Capacity

Assume use of largest windrow available: 100 feet x 12 feet x 4 feet = 4800 cubic feet

$$4800\ ft^3 \times \frac{1\ m^3}{35.31\ ft^3} = 136 \text{ cubic meters}$$

Average Density of Compost = 450 kg/m^3

$$450\ kg/m^3 * 136 \text{ cubic meters} = 61200\ kg * \frac{2.2\ lbs}{1\ kg} * \frac{.0005\ tons}{1\ lb.} = 67.32 \text{ tons}$$ → Waterman Capacity

Windrow and Density data provided by Dr. Fred Michel, associate professor of Food, Agriculture, and Biological Engineering at The Ohio State University.

Cost of Composting Pad

$$12 \text{ feet} * 100 \text{ feet} = 1200 \text{ square feet} * \frac{1\ acre}{43560\ ft^2} * \frac{\$200{,}000}{1\ acre} = \$5{,}509.64$$