Integrated Waste Management at The Ohio State University:
Economic and Institutional Determinants of Sustainability

Submitted to

The School of Environment and Natural Resources Honors Committee

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by

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Abstract

The purpose of this project is to explore potential pathways by which The Ohio State University (OSU) can lessen its ecological footprint by working within the bounds of current economic and institutional constraints. Two tools are central to this analysis: an EcoFlow^{TM} network designed to model the University's waste management system and a survey instrument used to identify both common challenges and best practices encountered by OSU's benchmark institutions as they have "greened" their campuses.

EcoFlow^{TM} provides a method by which both economic and ecological impacts for systems may be compared in numerical terms. Iterative calculations allow for the program to optimize the waste streams included in the model so that either cost or ecological impact is minimized. The material flow of greatest interest in this case is that of organic wastes, which are currently treated as mixed solid waste and sent to a landfill, but have the potential to be treated as commodities and greatly reduce the environmental impact of OSU's waste.

The survey instrument was distributed to solid waste managers responsible for recycling and other waste diversion programs at Ohio State's benchmark institutions. Because the tasks of waste management and, more broadly, institutional change are particularly challenging at institutions with large geographic areas and student populations, this respondent group was selected in order to identify trends and methods most likely to benefit *this* university.

Results suggest that although organic waste diversion to an anaerobic digestion facility would not reduce waste management costs, at least in the short run, it would allow for a considerable reduction in greenhouse gas (GHG) emissions attributed to OSU's waste generation, potentially equaling 3,102.54 $MTCO_2E$ metric tons of carbon dioxide equivalent ($MTCO_2E$) annually.

In addition, by recycling, Ohio State saves 3,550.53 $MTCO_2E$ annually. Improving recycling rates on campus could contribute significantly to reducing the University's GHG emissions using a readily available and operational system. Survey responses suggest that consideration should be given to the following characteristics: dissatisfaction with the status quo; financial constraints; student engagement; administrative support; stakeholder collaboration; clear statement of and commitment to sustainability objectives; and energy conservation as a priority.

Introduction

Conservation practices have long been considered costly elements of large institutional systems. While it is profitable to recycle certain materials, waste management typically represents a significant expense for businesses and institutions like Ohio State University (OSU). Recent developments in waste flow analysis, notably the EcoFlow^{TM} model developed through the Center for Resilience at OSU, allow for economics-based waste stream optimization and resilience calculations.

Industrial ecology was first defined as "the means by which humanity can deliberately and rationally approach and maintain a desirable carrying capacity…it is a systems view in which...factors to be optimized include resources, energy, and capital" (Allenby, 1999; Graedel & Allenby, 2003). This definition has since been adjusted to conform to the various contexts in which it is applied. In the case of universities and their waste management practices, the university is viewed as a closed system in terms of financial costs, and as part of a larger network in terms of ecological impacts. Put simply, a market exists for waste disposal but a market for greenhouse gases and other negative externalities has yet to be established. The waste management market is, in large part, the foundation for the modeling and optimization component of this analysis. Emissions control, ecological footprints, and other university policy issues are subject to more socially variable constraints. The interview portion of this analysis is designed to identify the groups, activities, political climate, and other characteristics that have led certain universities toward sustainable practices and policies. A common theme among the various definitions of industrial ecology is the concept that, "industrial ecology strives to be objective, not normative…where cultural, political, or psychological issues arise in an industrial ecology study, they are evaluated as objective dimensions of the problem" (Allenby, 1999). Accordingly, this analysis consists of two components so that a more complete conclusion may be drawn.

Past research conducted using the EcoFlow^{TM} model and data drawn from the University's waste management records suggests that, if certain alterations are made to waste management practices, financial savings could exceed $290,749, or ninety percent, annually (Naumoff 2007). A previous analysis included solid waste, recyclables, organic waste, and electronic waste from six sources on campus: residence halls, academic buildings, laboratories, recreation facilities, dining facilities, and maintenance buildings. This examination seeks to narrow this data and adjust the EcoFlow^{TM} tool so that it is available to the University's Office of Energy Services and Sustainability within the upcoming year so that theory may be transformed into movement toward a more sustainable campus.

Two questions lie at the core of this research. First, of the suggested waste diversions, which are most readily implemented and how can the computer model be adjusted accordingly? Second, what are the institutional facilitators and barriers to implementation of conservation practices associated with this system, and to what degree do they transcend finances? It is anticipated that the model will provide an economic justification for modifications to the University's waste management practices, but numerous other factors are expected to significantly influence implementation. Among these variables are: degree of emphasis on and demand for conservation initiatives among students, faculty, staff, and administrators; budgetary priorities; media and other external attention; academic significance; and others. The first is answered largely by computer modeling and numerical data, and the second requires analysis of a series of interviews and examination of other universities' waste management and conservation practices.

Literature Review

A great deal has been written about the emergence of sustainable solid waste management practices and their implementation by U.S. colleges and universities. Just as "sustainability" has become a buzzword in higher education, not to mention business and government, waste management operations oriented toward "cradle-to-cradle" resource management have begun to provide opportunities to "green" solid waste. A number of trends have been identified as characterizing colleges that have made progress in environmental stewardship, as well as their waste management strategies.

Upon recognizing the potential for significant improvements in environmental awareness and action at the university level, Pennsylvania State University (PSU), a large public institution comparable OSU, established the Green Destiny Council, a collaboration between students, staff, and faculty. The Council established a list of thirty-three sustainability indicators and has taken four steps toward sustainability: completion of an indicators report, development of an ecological mission, adoption of the mission by the University's Senate and President, and establishment of a finance and business strategy for environmental stewardship (Uhl & Anderson, 2001; *Penn State Indicators Report*, 2000). Initially, the University gauged its operations in the context of sustainability and found a significant deficit. Indicators included energy, water, land use, transportation, building management, and waste management. The ecological mission statement proposes methods for reducing consumption of a variety of resources. In discussing organic waste management, for instance, the report suggests reducing initial consumption, as well as purchasing biodegradable products (*Green Destiny*, 2000). The Penn State case is probably reflective of the challenges encountered and potential strategies employed by OSU, and provides some insight into the methods by which OSU could become more sustainable.

The literature predicts several broad trends that are expected to facilitate the implementation of sustainable practices at colleges and universities. These include: commitment to environmental action on the part of administrators; establishment of an environmental policy statement with broad input; creation of a university-wide environmental committee; and development of campus jobs with environmental leadership responsibilities (Creighton, 1998). Case studies have shown that in order to institutionalize sustainability, it is essential that corresponding indicators be developed and used (Barlett & Chase, 2004), as in the Penn State system. It has also been reported that universities that have acted as "environmental leaders" are frequently characterized by participation in information and best practice sharing with other institutions, a full-time environmental management staff, and responsibility for reporting to an authority such as a board of governors or board of regents (Allwright & Allwright, 2000).

Velazquez et al. (2005) identify common obstacles to the implementation of sustainable practices in higher education, including: lack of awareness, interest, and involvement; decentralized organizational structure; lack of funding; lack of support from university administrators; lack of data access; resistance to change; lack of performance indicators; and lack of policies to promote sustainability on campus. Lack of time and resources, particularly funding, is frequently cited as a challenge, even when staff have the necessary skills and knowledge to perform cost-benefit analyses and other assessments necessary for environmental management (Allwright & Allwright, 2000). The non-binding nature of related declarations and agreements has been found, in the absence of accountability measures, to hinder progress (Bekessy et al., 2007). Bekessy et al. (2007) also suggest that depending on bottom-up approaches or small-scale, gradual programs to introduce environmental stewardship allows universities to "greenwash" and does not yield measurable improvement. Abstract objectives and a primary focus on environmental education can be similarly unconstructive, and quantitative resource consumption objectives and monitoring are recommended to facilitate measurable progress. Finally, a widespread lack of awareness among administrators and staff related to the potential to reduce ecological and financial costs simultaneously is highlighted as a significant obstacle to sustainability programming (Dahle & Neumayer 2001).

A particularly challenging element of "greening" universities is the need for a transition toward sustainable waste management practices. Recycling programs typically focus on just a few of the potentially recyclable materials, such as paper and cardboard, and are often poorly publicized. In addition, there is far more progress to be made in exploring organic waste diversion, source reduction, and waste stream auditing (Dahle & Neumayer 2001). However, a number of U.S. colleges have taken on this challenge, and have experienced a great deal of success. The University of Colorado at Boulder (CU), for instance, has diverted over 19,000 tons of paper and 8,000 tons of co-mingled containers from the landfill, saving the equivalent of 18,775 metric tons of greenhouse gas emission since the implementation of its recycling program and reduced waste management costs by approximately $235,000 annually (Newport, 2006). Other U.S. Institutions have attained similar benefits through waste diversion practices, revised purchasing policies, education and outreach, and a variety of other activities.

Organic waste diversion provides a particularly interesting set of success stories related to university solid waste management. Composting, in some cases student-organized, is a rapidly spreading practice accompanied by unique challenges. Among these is the need for biodegradable food packaging and utensils, which are now available in the form of bioplastics synthesized from corn, sugar, potato, and other starches. The University of Massachusetts at Boston (UMASS), for instance, introduced biodegradable dinnerware in order to reduce the estimated 50 tons of polystyrene waste produced by the University's dining operations and facilitate composting practices (NWF, 2006). Despite the higher cost associated with bioplastics, the simplified compost process and student awareness generated by the project justified the investment. In addition, it has been noted that purchasing is a central determinant of universities' impacts on the environment; the PSU Green Destiny Council has emphasized that, "Because of its size and prestige, Penn State, alone, is capable of sending strong signals to its suppliers; and the combined economic power of America's 3,800 colleges and universities – $185 billion in annual buying and investments – coupled with their role as molders of vision and character, puts them in a unique position to promote a culture of minimum waste throughout the nation" (*Green Destiny*, 2000).

An emerging opportunity for both organic waste diversion and responsible purchasing for institutions without composting programs is anaerobic digestion (AD). Although Rutgers University manages a relatively small anaerobic digestion system, there are few examples of colleges using AD programs to divert their entire organic waste streams despite the relative popularity of composting. However, AD facilities are commonplace in Europe and are beginning to appear at a municipal scale in the United States, which will make them increasingly accessible to the nation's colleges.

Anaerobic digestion is a process by which microorganisms metabolize organic matter, including wastewater and food wastes, in an oxygen-free environment, thereby producing biogas and organic solids (Reith et al., 2003). The process is considered to be technologically simple with low energy input requirements. The gas produced can be used as fuel, while the solids are potentially valuable as fertilizers and topsoil amendments. The biogas is composed of methane (CH_4) and carbon dioxide (CO_2), as well as trace amounts of nitrogen (N_2), hydrogen (H_2), hydrogen sulfide (H_2S), water vapor, and other gases. For energy production, biogas can be captured directly from the reactor and used at an on-sight generator or sold to natural gas consumers.

According to an analysis conducted by the Australian Government's Department of the Environment, Water, Heritage, and the Arts (DEWHA), for waste sent to a landfill rather than an anaerobic digester, only about 50% of the available carbon is converted to methane, which suggests a greenhouse emissions savings of 0.085 kg methane per kilogram of waste. This figure is multiplied buy 21 to derive CO_2 equivalents. Accordingly, for each metric ton of waste processed via anaerobic digestion rather than landfilling, the greenhouse saving is 1.785 metric tons of CO_2 equivalent emissions. This figure appears somewhat high compared with others calculated for analogous processes. It has also been approximated, for instance, that, "If you treat a tonne of food waste using anaerobic digestion producing heat, you save roughly a tonne of carbon dioxide equivalent" (Gyekye, 2007). A 2006 report also suggests that, accounting for both landfill diversion and energy production, approximately 1.1 $MTCO_2E$ is abated for each metric ton (1.0 $MTCO_2E$ per short ton) of food waste processed via anaerobic digestion (Levin 2006).

While the benefits of relying upon anaerobic digestion rather than landfilling are relatively clear-cut, the advantages of AD relative to composing, as revealed by the literature, are perhaps less intuitive. While composting is an energy-consuming process, requiring 50-75 kWh per metric ton of organic waste input, AD is a net energy-producing process, generating 75-150 kWh per metric ton of mixed solid waste (WASTE 2008). Richardson (1996) highlights the major benefits of the process as: less biomass produced per unit of substrate utilized; economic value of biogas; high organic loading potential; and simplicity of biomass-to-fuel processing. Reith et al. (2003) add to this list of advantages, explaining that anaerobic waste treatment processes typically consume little energy relative to alternative treatments; produce relatively odor-free end products; exhibit a very high retention rate for fertilizer nutrients (nitrogen, phosphate, and potassium); and impose relatively low facility space requirements and construction costs. Haight (2005) conducted a lifecycle analysis (LCA) study to compare the environmental impacts of four solid waste management options for the organic portion of a municipal solid waste stream: landfilling; landfilling with energy recovery; composting; and anaerobic digestion. The results suggest that while composting is preferable to both landfill options in terms of greenhouse gas emissions, anaerobic digestion is superior to all three alternatives based on avoided greenhouse gas emissions and avoided energy consumption. Murphy and Power (2006) describe similar results, concluding that because anaerobic digestion produces a fossil fuel substitute, it is environmentally preferable to composting.

The environmental benefits of anaerobic digestion are closely associated with the production of biogas, which consists of methane, carbon dioxide, and trace elements, and its conversion to energy. Biogas an alternative to fossil fuels and has the potential to provide enough energy to operate the digester and produce an impressive surplus.

The DEWHA analysis (2008) provides the following estimates on biogas recovery and energy production from anaerobic digestion. These calculations assume a composition of primarily green waste and food waste and operation under thermophilic conditions (55-57^{o}C) like those of the Kurtz facility being constructed in Columbus.

Quantity of methane = 0.17 kg per kg of waste

Energy potential of 1 m^3 methane is ≈ 33,810 kJ / m^3

1 m^3 methane = 0.672 kg

Energy potential of 1 kg of methane is = 50,312.5 kJ / kg

Energy potential per kg of organic solid waste is = 0.17 x 50,312.5 kJ = 8,553 kJ = 2.38 kWh
1 metric ton = 1000.00 kg
Energy potential per metric ton of organic solid waste is = 1000.00 x 2.38 kWh = 2380 kWh

Another estimate by the Waste Advisors on Urban Environment and Development suggests that one metric ton of food waste typically produces 100 m^3 biogas, with an energy value of 21,000-28,000 kJ/m^3, or 584.36-779.14 kWh per metric ton of solid waste (WASTE, 2008). Using the ratio 73% methane to 27% carbon dioxide by volume, Frigon and Guiot (2005) found the average energy content of biogas produced from food waste to be 27,200 kJ/m^3, based on the 73% methane content and 37,300 kJ/m^3 energy content of methane. The U.K. Department for Environment, Food and Rural Affairs (DEFRA) suggests a slightly lower energy production value for the anaerobic digestion of food waste, estimating a yield of 46 m^3 per metric ton and 21,000-25,000 kJ/m^3 (*Potential Feed*, 2008).

Methods

Economic Analysis

The economic analysis included in this project consists of assessments of both the economic and ecological costs of solid waste management at Ohio State University. The EcoFlow™ program was developed by researchers at Ohio State's Center for Resilience and is used to establish an industrial ecology network to model the University's waste flows. The program, which is based on a linear programming structure, provides four different objective functions that may be used to solve the model, including maximizing profit, minimizing total cost, maximizing mass flow, and minimizing eco-impact. In this case, the objectives of interest are minimizing total cost and minimizing eco-impact. The EcoFlow™ model is particularly useful for this analysis as it provides a method by which variations in OSU's waste flows, whether related to cost, collection, or ecological impacts, may be changed with relative ease and the model may be re-solved. The University's waste management system is constantly evolving and the model has the potential to account for fluctuations. In addition, it provides a mechanism by which different methods of managing the system may be compared. In this case, the model is used for two purposes. The first is to establish a baseline scenario that recreates the system currently in place to illustrate the validity of the model, which may then be manipulated. The second application is designed to demonstrate the impacts – both financial and ecological – of diverting organic waste from the mixed solid waste stream to an anaerobic digester.

Components of the model: This model consists of a number of relatively simple components that may be associated graphically and mathematically to optimize waste flows.

1. *Input nodes*: The input nodes in this model are the original waste sources: residence halls, academic buildings, laboratories, maintenance facilities, recreation facilities, and dining facilities. The waste from theses sources is divided into more specific categories of materials, which are designated allocation nodes.

2. *Allocation nodes*: The first set of allocation nodes for the single-stream system consists of: mixed solid waste, recycling, cardboard, and organic waste. Allocation nodes are generally followed by conversion processes, which implies that the products of such processes are further divided into other products. In some cases, however, materials are sent through another allocation process. Secondary allocation processes include Republic Waste Services collection, the Reynolds Avenue transfer station, and organic solids.

3. *Conversion nodes*: Conversion processes are, as their name suggests, those in which an incoming waste is processed into a preferred (more valuable or more environmentally benign, for instance) product. While some conversion nodes are connected directly to output nodes, which represent a profitable final product, others lead to allocation nodes, which implies that the final product of the conversion process is divided into multiple end product commodities. Conversion processes associated with the single-stream system include: Rumpke recycling, SWACO landfill, Kurtz Bros., Inc. anaerobic digestion (AD) facility, and biogas produced by the AD process.

4. *Output nodes*: The final products, or profitable commodities, resulting from the allocation and conversion processes drive the optimization. They determine the viability of the preceding processes, many of which have some cost associated with processing and/or transportation. Because the prices of these commodities fluctuate, some variability in accuracy is to be anticipated. Outputs include: paper, plastics, cardboard, mixed metals, cardboard, fertilizer, methane, and carbon dioxide.

5. *Arcs*: Arcs connect the various processes included in the model and are used to create a visual-mathematical map of material flows. Like the nodes, arcs may be constrained by diversion ratios and transportation costs and constraints. In this model, transportation costs are modeled on the corresponding arcs. Certain processing costs are also modeled using arcs.

Data was obtained largely by reviewing records maintained by Ohio State's Department of Facilities Operation and Development (FOD) and interviewing FOD staff. The following records were used to calculate transport costs and associated emission for waste within the University's system: truck operation hours; truck maintenance and repair costs; collection staff hours and corresponding costs; fuel purchase records; weight tickets; quantities of cardboard, commingled recycling, and mixed solid waste collected; and the number of stops required weekly for these materials. In addition, U.S. Foods, which provides the plastic flatware and disposable packaging used in the University's dining facilities, provided purchasing data on these products. Data was drawn largely from calendar year 2007, although certain records provide fiscal year data (July 2006 through June 2007).

Institutional Analysis

The institutional analysis is intended to provide a qualitative description of the ways in which U.S. colleges and universities are working to integrate sustainability concerns into their solid waste management systems. Clearly, there are factors beyond financial concerns and logistics involved with the movement toward sustainability in solid waste management, particularly at educational institutions. The EcoImpact function included in the computer model accounts, in a very practical sense, for the ecological impact of certain waste management activities and systems. However, in order to more closely examine the institutional determinants of sustainability, a survey (Appendix B) was administered to recycling coordinators and other solid waste managers at institutions considered to be benchmarks relative to Ohio State (HRITS, 2007). Benchmarks were chosen in order to provide insight into how universities that have many institutional characteristics in common with Ohio State have worked to "green" their waste management systems and how OSU might apply these lessons.

Recycling coordinators or waste managers responsible for recycling programs at each institution were contacted via e-mail with a request that they participate in the survey process. Surveys were sent via e-mail to those who responded positively, and follow-up surveys were sent to those who agreed to participate but did not complete the initial survey. A pre-test was not conducted due to time constraints.

The first portion of the survey is designed to provide information on recycling rates, the frequency of commingled versus separated collection systems, and changes in recycling rates that have occurred at these institutions in recent years. Subsequent questions are intended to reveal the influence, as perceived by university solid waste managers, of factors such as student involvement and educational programming, infrastructure, and administrative and other support. Because only twelve surveys (39% response rate) are included in this review, statistical analysis is not necessarily applicable, but surveys provide qualitative data that can also be used to describe trends.

Data

Economic Analysis

<u>Waste Generation</u>

Total Waste Collected (from FOD records for 11/08/06 - 11/08/07; recorded as commingled recycling, cardboard, front-loading trash collection, and rear-loading trash collection):

Trash (rear-load and front-load)	5876.00 tons
Commingled recycling	930.57 tons
Cardboard	598.31 tons
Total:	7404.88 tons

Mixed Solid Waste

According to estimates from a previous analysis (Naumoff, 2007), the solid waste (including organic waste) collected on campus is divided approximately as follows:

Residence halls:	53.50%	3143.47 tons
Academic buildings:	30.24%	1777.03 tons
Laboratories:	1.68%	98.45 tons
Recreation facilities:	4.67%	274.83 tons
Dining facilities:	8.85%	519.95 tons
Maintenance buildings:	1.06%	62.27 tons

Commingled Recyclables

According to estimates from a previous analysis (Naumoff, 2007), the commingled recyclables collected on campus are divided approximately as follows:

Residence halls:	23.99%	223.24 tons
Academic buildings:	30.52%	284.01 tons
Laboratories:	0.00%	0.00 tons
Recreation facilities:	16.23%	151.03 tons
Dining facilities:	12.74%	118.55 tons
Maintenance buildings:	16.52%	153.73 tons

Organic Waste

Organic wastes produced by Ohio State include food waste, yard waste, and wood products. This analysis focuses primarily on food waste, which is currently collected as mixed solid waste, as the other types of organic wastes mentioned are already separated and managed as commodities. The University collects yard waste, of which 217.50 tons was produced in 2006, to be processed and used for landscaping on campus. Damaged pallets and other wood products are processed along with these lawn wastes for the same purpose, while functional pallets are purchased by Able Pallet Manufacturing and Repair.

The most significant producers of organic waste on campus at Ohio State are dining halls, residence halls, and recreation facilities' dining areas. The University currently maintains 15 dining facilities, including the dining area located in RPAC (Courtside Café and Juice 2). Organic wastes produced in dining halls and athletic facilities consist of kitchen preparation waste and leftovers thrown out by customers. Not surprisingly, dining areas in which food is prepared as ordered, rather than served buffet-style, typically produce less discarded organic matter. In addition, certain dining facilities provide carry-out options alone, which suggests that their predominant organic waste source is food preparation. The widespread availability of takeout service also implies that the corresponding food waste is distributed elsewhere on campus, including residence halls. Under the current system, food waste is either placed in trash containers or sent through a garbage disposal. It is somewhat more difficult to characterize the organic waste produced by residence halls than dining facilities, as waste audits have not been conducted at Ohio State to provide this information.

Although comprehensive waste audits have been conducted to determine the proportion of the mixed solid waste stream at each dining and residence accounted for by organic waste, Naumoff (2007) estimates that OSU dining halls produce 225.97 tons of food waste annually, while recreation facilities (specifically the Recreation and Physical Activity Center, or RPAC) create 4.52 tons. Because this data is relatively incomplete, results from other universities' waste characterizations studies are used to make approximations related to the sources of organic waste on campus.

In March 2007, the University of Michigan's (UM) Waste Management Services Department conducted a refuse sort to acquire data on the composition of six building types on the Ann Arbor campus (Artley, 2007). These building categories include: administrative; classroom; research; residence; unions; and recreational. One representative building was selected from each category and for a period of one week refuse from these buildings was sorted into 12 categories, including compostable organic waste (defined as "non-recyclable organic items which are acceptable in the UM Food Waste Composting Program…pre-consumer vegetative food waste, plain rice and bagels") and non-compostable organic waste (defined as "non-recyclable organic items not currently compostable within the UM Food Waste Composting Program…post-consumer foods, fats, oils, greases, meats, etc."). This study is of interest in the context of organic waste analysis at Ohio State because UM is a large, public university and is considered to be among OSU's benchmark institutions. According to the report, approximately 45.2% of refuse produced at the Ann Arbor campus, by weight, is composed of organic or compostable waste. The study also found that the proportion of the typical mixed solid waste stream accounted for by organic waste is: 34% for classroom buildings; 73% for research buildings (life science); 35% for residence halls; 55% for unions; and 28% for recreational facilities. Interestingly, the UM report concludes with a series of recommendations including exploration of anaerobic digestion options for organic waste.

A similar waste characterization study was conducted at the University of Washington's (UW) Seattle campus in 2003 (Cascadia, 2003). This analysis, which included a larger number of buildings and longer data gathering period than the UM study, determined that compostable wastes account for approximately 46% of the University's total waste stream. This figure includes materials other than organic waste, which composes the following proportions of the UW refuse stream: 24% for classroom buildings; 22% for laboratory buildings; 34% for residence halls; and 30% for athletic facilities; 38% for food services operations; and 11% for maintenance buildings. These figures are relatively similar to those recorded for UM, with the exception of laboratory buildings. A potential explanation for the large proportion of organic waste at UM labs is the use of a life sciences facility, which likely produces more organic matter than physical science and engineering labs, for extrapolation.

Using estimates (percentages) based upon the data collected at the University of Washington for OSU:

Residence halls:	34.00% x 3143.47 tons	= 1068.78 tons organic waste
	3143.47 tons - 1068.78 tons	= 2074.69 tons MSW
Academic buildings:	24.00% x 1777.03 tons	= 426.48 tons organic waste
	1777.03 tons - 426.48 tons	= 1350.55 tons MSW
Laboratories:	22.00% x 98.45 tons	= 21.66 tons organic waste
	98.45 tons - 21.66 tons	= 76.79 tons MSW
Recreation facilities:	30.00% x 274.83 tons	= 82.45 tons organic waste
	274.83 tons - 82.45 tons	= 192.38 tons MSW
Dining facilities:	38.00% x 519.95 tons	= 197.58 tons organic waste
	519.95 tons - 197.58 tons	= 322.37 tons MSW
Maintenance buildings:	11.00% x 62.27 tons	= 6.85 tons organic waste
	62.27 tons - 6.85 tons	= 55.42 tons MSW

Cardboard

A previous analysis of the University's waste network accounted for cardboard collected from dining and residence facilities at OSU. However, FOD maintains data on the number of collection stops made per week for trash, commingled recycling, and cardboard, and these records suggest that all six types of buildings considered here generate cardboard. Because data on the amount of cardboard collected from each building or type of building is unavailable, data from other university waste audits is used to make approximations.

According to a solid waste audit conducted at the University of Michigan in 2007, cardboard represents approximately 4% of the solid waste collected from research buildings (laboratories in this case), 7% from residence halls, and 5% from recreation facilities (Artley, 2007). Data collected at the University of South Florida suggests that cardboard accounts for approximately 10% of the waste generated in campus academic and administrative buildings (Tougas et al., 2007). In addition, Naumoff's (2007) estimates suggest that cardboard accounts for approximately 9% of the dining facility waste stream. Using estimates (percentages) based upon these studies:

Residence halls:

0.93n = (2074.69 tons MSW + 1068.78 tons organic + 223.24 tons recyclable)

n = total solid waste = 3620.12 tons

n - 2074.69 tons MSW - 1068.78 tons organic - 223.24 tons recyclable = 253.41 tons cardboard

Academic buildings:

0.90n = (1350.55 tons MSW + 426.48 tons organic + 284.01 tons recyclable)

n = total solid waste = 2290.04 tons

n - 1350.55 tons MSW - 426.48 tons organic - 284.01 tons recyclable = 229.00 tons cardboard

Laboratories:

0.96n = (76.79 tons MSW + 21.66 tons organic + 0.00 tons recyclable)

n = total solid waste = 102.55 tons

n - 76.79 tons MSW - 21.66 tons organic - 0.00 tons recyclable = 4.10 tons cardboard

Recreation facilities:

0.95n = (192.38 tons MSW + 82.45 tons organic + 151.03 tons recyclable)

n = total solid waste = 448.27 tons

n - 192.38 tons MSW - 82.45 tons organic - 151.03 tons recyclable = 22.41 tons cardboard

Dining facilities:

0.91n = (322.37 tons MSW + 197.58 tons organic + 118.55 tons recyclable)

n = total solid waste = 701.64 tons

n - 322.37 tons MSW - 197.58 tons organic - 118.55 tons recyclable = 63.15 tons cardboard

Maintenance Buildings:

The remainder of the cardboard collected, which totaled 598.31 tons between November 8, 2006 and November 8, 2007, is allocated to the remaining input node, maintenance buildings

598.31 - (253.41 + 229.00 + 4.10 + 22.41 + 63.15) = 26.24 tons cardboard

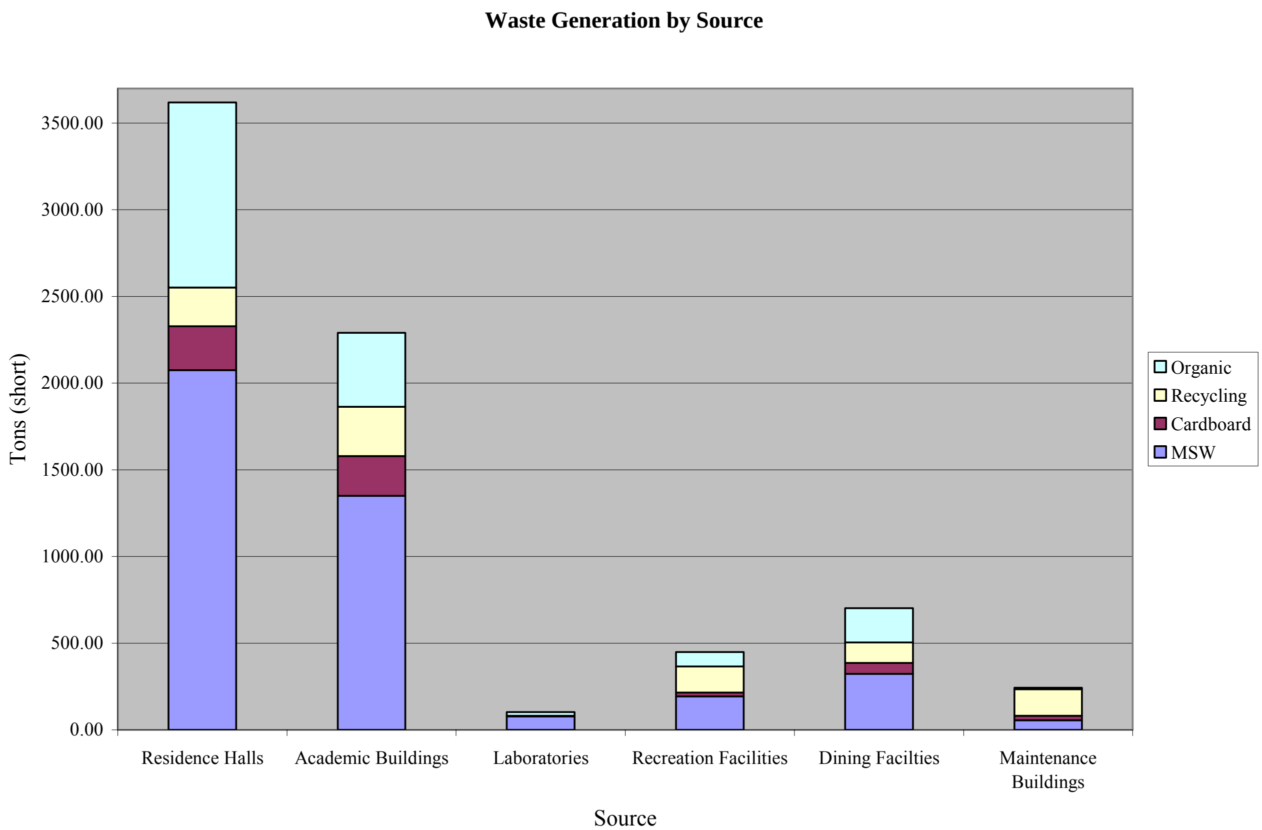

Figure 1. Waste generation by source at Ohio State. Excludes electronic waste, scrap metal, and pallets.

Electronic Waste

Electronic waste is collected by OSU Surplus Materials Disposal, which is located at 2560 Kenny Road in Columbus. University departments, all of which produce electronic waste, may deliver items to the warehouse directly or contract with commercial movers (Tiburzi, 2008). OSU Surplus receives approximately 18,000 pieces of electronic equipment per year. The average 15-inch computer monitor weighs approximately 28 pounds (Drake 2007). Assuming this is the typical electronic item brought to Surplus, the Department collects approximately 252 tons of electronic waste per year. Approximately 60% of these electronics are recycled while 40% is stored in the warehouse for transfer to other OSU departments or sale to entities outside of the University. Recycled materials consist of metals and other products, but the proportion of the electronic waste stream composed of each material is unknown. Of the electronics retained by Surplus, approximately 25% is redistributed within the University and 75% is sold to the public.

Prices for electronics sold to the public are established based upon quality and comparison to competitors' prices. In 2007, resale of items brought to Surplus generated $80,000 in revenue. Because approximately 30% (75% x 40%) of the electronics that enter Surplus are sold to the public, and this is estimated to be around 75.6 tons, the approximate price (revenue) per ton for refurbished electronics is $1,058.20 per ton.

The surplus department does not charge or pay for departmental equipment transfers, and there is no cost for shredding hard drives. The University's Environmental Health and Safety Department contracts with Shredder to dispose of computer monitors and printers at a cost of $75.00 per ton. Intechra collects the recyclables for $100.00 per ton. According to Naumoff (2007), the ratio of material sent to Shredder to material send to Intechra is approximately 5:3.

The value of reassigned electronics that are put to new uses by the University is difficult to estimate because it is unclear whether new equipment would be used if surplus were unavailable, or if old equipment would simply be retained.

Pallets

Ohio State's solid waste stream includes wood pallets used throughout campus. Able Pallet Manufacturing & Repair collects wooden pallets from OSU to be recycled. The University is paid $1.50 for each pallet and each pallet weighs approximately 20 pounds, which implies a commodity value of $150 per ton. Between February 5, 2008 and March 21, 2008, Able collected 796 pallets, totaling 5.68 tons, from OSU. This 46-day period is used to extrapolate in order to estimate the tons collected annually from OSU: (5.68 tons / 46 days) x 365 days = 45.1 tons per year

Scrap Metal

Masser Metals & Recycling collects scrap metal from Ohio State and the University receives payment for this. Data on the allocation of scrap metal at OSU is unavailable, and according to FOD, is collected from nearly all areas and types of buildings on campus because its sources range from filing cabinets to remodeling and construction debris. The campus-wide collection of scrap metal appears to be declining, as shown by data from fiscal years 2002-2007. The price paid for the metal, however, has increased according to market value, rising from approximately 2.6 cents per pound in fiscal year 2006 to 3.5 cents per pound in 2008 (Hoff 2008).

FY	2003	2004	2005	2006	2007	7/07 - 2/08
Tons Metal	140.53	134.99	128.35	117.18	38.98	9.39

Table 1. Scrap Metal recycled by OSU annually through Masser Metals.

For the sake of simplicity, electronic waste, pallet, and scrap metal collections are omitted from the model because there is no decision at hand concerning their allocation. However, because a commodity value is associated with each of these materials, they have the potential to reduce overall costs if included in the model. Specific calculations would require that the commodity values, as well as staff hours and transportation needs, be included as well.

Costs: Waste Disposal

Landfill: Republic Waste Services & SWACO

Most of the solid waste produced at Ohio State is sent to a landfill operated by the Solid Waste Authority of Central Ohio (SWACO), which is located on the south side of Columbus. However, the University depends upon Republic Waste Services to transport this waste either directly from campus or from a transfer station to the landfill. Republic transports mixed solid waste and construction waste stored in compactor boxes and open-top 20-yard boxes that cannot be transported by the University's own truck fleet. Republic delivers this waste either to the Reynolds Avenue transfer station, which is owned by Republic, or to the SWACO landfill. Some waste is also transported to Reynolds by OSU vehicles. For waste hauled to Reynolds or SWACO by Republic, the University incurs four types of fees, which account for delivery, hauling, tonnage, and fuel/environmental, respectively. Hauling fees are based on the number of collections and tonnage fees are $33.40 per ton for construction and debris trash and $34.50 per ton for mixed solid waste trash. Fuel/environmental fees are calculated based on the total number of pulls at a cost of $15.45 per pull. For waste transported by Republic, the University pays $118.45 for loads taken to the transfer station and $146.45 for loads taken to the landfill (Hoff, 2008). Using data from 2007, the average number of tons per pull is 4.35, which implies that the cost to OSU per ton transported by Republic is ($118.45/4.35) + $34.50 = $61.73 for mixed solid waste taken to the transfer station and ($146.45/4.35) + $34.50 = $68.17 for mixed solid waste taken to the landfill.

Ohio State vehicles are also used to deliver mixed solid waste to the Reynolds transfer station at a cost of $50.75 per ton. According to Naumoff (2007), approximately 20% of the University's mixed solid waste is collected by Republic and taken to the Reynolds transfer station or landfill. Records provided by FOD suggest that this proportion ranges from 15% to 25% (Hoff, 2008). While the cost per ton is consistent as a result of this standard fee, the number of trips taken to Reynolds by OSU vehicles introduces some variability in cost from truck fuel and maintenance. As of March 12, 2008, tons per load delivered to Reynolds by OSU in fiscal year 2008 have ranged from 3.88 to 6.58.

A notable benefit of having waste hauled from campus to a disposal site by Republic is a potential savings resulting from reduced labor cost. The total labor cost for mixed solid waste collection with a front-loading truck between November 8, 2006 and November 8 2007 was $146,577.60 to collect 4,160 tons according to FOD records. Because it is anticipated that fewer University staff hours will be necessary to manage waste being collected by an external contractor, the allocation node representing Republic is given a cost of -35.24 per ton, which represents the cost per ton saved by not having OSU staff collect trash in the typical front-load vehicles. Truck costs assigned to the University, however, cannot be ignored in this case because Republic requires that the University pay fuel fees for its collection services.

Recycling: Rumpke

Commingled recyclables, which include mixed office paper, newspaper, #1 and #2 plastics, aluminum, glass, and some cardboard, are sent to Rumpke to be processed for a tipping fee of $10.00 per short ton. The only recyclable material for which Ohio State receives payment is cardboard collected separately from the commingled system. The University receives $68.00 per ton for cardboard, but the per ton value is $58.00 since the $10.00 fee is also applied to cardboard. Lack of storage space for recyclable cardboard has been noted as a challenge at OSU, and FOD is currently considering the purchase of balers.

Anaerobic Digester: Kurtz Brothers, Inc. AD Facility

It is anticipated that, initially, tipping fees would be competitive with those of the landfill (Kurtz, 2008). Accordingly, the SWACO landfill tipping fee, currently $33.50 per short ton, is applied to the anaerobic digestion process in order to generate conservative estimates. However, the facility's ability to produce and market commodities like fertilizer and fuel, as well as the operators' continued investigation into emerging collection processes, are likely to reduce the overall cost of operation at the facility. In addition, the digester will be located somewhat closer to campus than the SWACO landfill, and because the University is responsible for transporting waste to the site, this could provide cost savings in terms of fuel consumption. It is anticipated that additional digesters will be constructed in Columbus, which would make anaerobic digestion accessible not only to OSU, but also to businesses located in other areas of the city.

In order to process organic waste produced on campus via anaerobic digestion, the waste streams would have to be modified. Food, paper, and other readily biodegradable materials can be processed with the digester, but plastic and Styrofoam cannot. In order to establish a wholly biodegradable waste stream from dining areas, plastic and Styrofoam utensils and containers would have to be replaced with organic-based substitutes such as bioplastics for carry-out style meals. Bioplastics are plastics made from renewable sources such as corn starch and vegetable oil rather than petroleum. Among these compostable plastics, three types have received a great deal of attention in recent years: poly(hydroxyalkanoates) (PHA), polylactic acid (PLA), Poly-β-hydroxybutyric acid (PHB), and thermoplastic starch (TPS) (Comstock et al., 2004). Disposable utensils and packaging made from these bioplastics are currently available, but because of the size of the University and its food services operation, waste managers have expressed concerns related to both cost and availability.

Concerns related to the cost of bioplastic packaging are apparently legitimate; PLA resins cost around 25% more than petroleum-based resins, and the finished, biodegradable plastic products sold to consumers may cost twice as much as comparable polyethylene products (Comstock et al., 2004). NatureWorks™, formerly Cargill Dow, is the world's largest producer of PLA. The company sells bioplastics and other bio-based packaging to large companies like Wal-Mart and Wild Oats, as well as a number of partner companies that distribute specialty products. Among these partners is EcoProducts, Inc., which manufactures a wide variety of PLA food containers, which are substitutes for petroleum-based plastics, as well as sugarcane fiber-based polystyrene substitutes. The following is a cost comparison of standard materials and biodegradable materials for the food packaging items most commonly used at University facilities. It should be noted that, for the sake of simplicity, not all items purchased by Campus Dining Services (CDS) are included in this comparison. In addition, these data reflect CDS purchases only, which include dining facilities but do not reflect total purchases; accordingly, total purchase figures are conservative estimates.

Item	Cost[1]/1000 ct. (plastic)	Cost[2]/1000 ct. (biodegradable)	# (1000s) purchased by CDS 07/01/06 - 06/30/07	# (1000s) used/ton waste	Additional cost per ton organic waste (biodegradable)
Plastic Fork, Med. Weight[3]	$19.24	$49.46	1525.00	0.845437	$25.55
Plastic Spoon, Med. Weight	$14.29	$49.46	1282.00	0.710721	$25.00
Plastic Knife, Med. Weight	$19.95	$49.46	1105.00	0.612596	$18.08
Plastic Container[4]	$198.54 (12 oz)	$277.64 (12 oz)	805.13	0.44635	$35.31

[1] Cost data drawn from www.instaoffice.com and www.waresdirect.com.
[2] Cost data drawn from www.instaoffice.com and www.ecoproducts.com.
[3] Plastic flatware estimates include items purchased as part of packaged sets (knife, fork, spoon, napkin, for instance) and in different colors and weights (assumed white, medium weight polystyrene). This analysis does not account for the individual wrappers in which some disposable flatware is packaged.

Paper Cup (waxed)[5]	$123.67 (24 oz)	$147.70 (24 oz)	133.85	0.074205	$1.78
Plastic Cup	$91.61 (24 oz)	$147.70 (24 oz)	1291.20	0.715822	$40.15
Plastic Lid (cup)	$52.34	$59.96	914.65 [6]	0.50707	$3.86
Wrapped Straw	$11.54	$17.94	2097.88	1.16303	$7.44
Foam Entrée Container	$110.60	$321.00	493.80	0.27376	$57.60
Total additional cost per ton of organic waste from biodegradable packaging: $214.77					

Table 2. Disposable food packaging items commonly used on campus (Reithman, 2007).

Costs: Collection and Transportation

These costs are drawn from FOD records for November 8, 2006 to November 8, 2007. The Department operates two pickup trucks, three front-loading packer trucks, five rear-loading packer trucks, two box trucks, and one hard trash truck. Rear-loading trucks are typically used to transport commingled recycling, cardboard, and approximately 30% of the mixed solid waste collected. Front-loading trucks are used to collect the remainder of the mixed solid waste.

These calculations explain the dollar values assigned to the arcs connecting the input nodes to allocation nodes. Costs assigned to conversion nodes account for tipping fees, and commodity values are assigned to output nodes. It should be noted that if the costs were to be calculated without the model, the tipping fees ($10/ton for cardboard and recycling and $47/ton for mixed solid waste) would have to be added to, and commodity revenue subtracted ($68/ton for cardboard) from, the per-ton costs.

Front-Loading Packer Trucks: $25,662.09 (parts and labor) + $20,052.66 (fuel) = $45,714.75

Rear-Loading Packer Trucks: $31,638.14 (parts and labor) + $30,010.42 (fuel) = $61,648.52

Commingled Recycling (collected with a rear-loading packer truck)

(2,496 truck hrs/yr x $14.83/hr) + (3,536 labor hrs/yr x $34.80/hr) = $160,068.48/yr

($160,068.48/yr) / (930.57 tons) = $172.01/ton

Cardboard (collected with a rear-loading packer truck)

(3,328 truck hrs/yr x $14.83/hr) + (6,864 labor hrs/yr x $34.80/hr) = $288,221.44/yr

($288,221.44/yr) / (598.31 tons) = $481.73/ton

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[4] Total includes plastic clamshell containers of various dimensions and shapes.
[5] Total includes cups of various dimensions.
[6] Includes lids sold with paper cups.

Mixed Solid Waste, including organics (collected with rear- and front-loading packer trucks)

Rear-loading (RL) packer truck

(2,912 truck hrs/yr x $14.83/hr) + (6,656 labor hrs/yr x $34.80/hr) = $274,813.76/yr

($274,813.76/yr) / (1,716 tons) = $160.15/ton

Front-loading (FL) packer truck

(4,316 truck hrs/yr x $19.75/hr) + (4,212 labor hrs/yr x $34.80/hr) = $231,818.60/yr

($231,818.0/yr) / (4,160 tons) = $55.73/ton

A weighted average of these values is used to establish a single hourly cost for mixed solid waste collection. Because different trucks are used at different times to complete a particular route, it is not possible to assign front-loading or rear-loading trucks to particular arcs for mixed solid waste. Because the organic waste is currently collected as part of the mixed solid waste stream, the same cost per ton is used in the model. It should be noted that it would likely cost more to collect organic waste, as additional routes would have to be added to the current system.

4,160 tons (FL) + 1,716 tons (RL) = 5876 tons mixed solid waste

4,160 tons (FL) / 5876 tons = 70.80%

1,716 tons (RL) / 5876 tons = 29.20%

(0.2920 x $160.15/ton) + (0.7080 x $55.73/ton) = $86.22/ton

EcoImpacts: Collection and Transportation

The trucks used for collection are operated on B20 biodiesel fuel. The following conversions are provided by the U.S. Environmental Protection Agency and are established based upon data from the Intergovernmental Panel on Climate Change (IPCC) (EPA, 2005; Pachauri & Reisinger, 2008). EcoImpacts are expressed in terms of carbon dioxide equivalents, which are calculated by examining the relative global warming potential (GWP) of each greenhouse gas emitted and establishing a common metric. According to the IPCC, the GWP of methane (CH_4) is 21 and that of nitrous oxide (N_2O) is 310, while carbon dioxide (CO_2) represents the baseline GWP and is set at 1 (EPA, 2005).

Emissions associated with transportation are limited to CO_2 calculations, as this is the dominant GHG produced by diesel fuel combustion. The quantity of CO_2 released by trucks is proportional to the quantity of fuel used. Diesel combustion also releases the greenhouse gases N_2O, CH_4, and hydrofluorocarbons (HFC), but these are negligible in comparison with CO_2 release (Buttazzoni et al., 2003). As suggested by EPA guidelines, carbon monoxide (CO) and other greenhouse gases formed by atmospheric chemical reactions of compounds directly released by combustion are omitted from calculations (EPA 2005). CO_2 emissions produced by one gallon of fuel are calculated by multiplying carbon emissions by the ratio of the molecular weight of CO_2 (44.009 g/mol) to the molecular weight of C (12.011 g/mol). Diesel fuels derived from petroleum typically contain a mixture of C_{10} through C_{19} hydrocarbons, of which approximately 65% are saturated hydrocarbons and 35% are aromatic hydrocarbons (DHHS, 2007).

Because Ohio State's fleet is operated on B20 fuel, which is composed of 80% petroleum diesel and 20% biodiesel, it is assumed that emissions are approximately 80% of what they would be for pure diesel fuel in terms of CO_2 equivalents (Simonton & Skov, 2007). This approximation is based on the assumption that biodiesel greenhouse gas emissions are negligible. It should be noted that these calculations include the greenhouse gas emissions associated with combustion, but exclude the ecological impacts associated with production of petroleum diesel and biodiesel, which are beyond the scope of this analysis. The quantity of solid waste collected is described in terms of short tons, while emissions are expressed in metric tons of carbon dioxide equivalent ($MTCO_2E$).

CO_2 emissions from 1 gallon of diesel = 2,778 g C/gal x 0.99 x (44/12) = 10,084 g = 10.1 kg/gal = 22.2 lbs/gal

CO_2 emissions from 1 gallon of B20 fuel = (22.2 lbs/gal) x 80.0% = 17.8 lbs/gal

According to the U.S. Department of Energy, the average price of diesel fuel in the U.S. in 2007 was $2.86 (DOE, 2008). The average price of B20 per gallon was approximately equal to that of standard diesel in 2007; accordingly, $2.86 will be used for calculations (DOE, 2007). It should be noted that while diesel prices are much higher in 2008, this increases the cost of transportation for each process proportionately, raising the cost of the system overall but leaving relative costs essentially the same. The University's fleet of front-loading and rear-loading packer trucks consumed $57,300.23 worth of fuel between November 8, 2006 and November 8, 2007. During the same time period, 7,404.88 tons of commingled recyclables, cardboard, and mixed solid waste were collected with this fleet.

$50,063.08 / ($2.86/gal) = 17,504.57 gal
17,504.57 gal x (17.8 lbs CO_2/gal) = 311,581.35 lbs CO_2 = 155.79 tons CO_2
155.79 tons CO_2 / 7,404.88 tons collected = 0.021039 tons CO_2 / ton (average)
= 0.021039 $MTCO_2E$ / metric ton collected
= 0.023185 $MTCO_2E$ / short ton collected

Front-loading packer trucks were used to collect 4,160.00 tons and incurred $20,052.66 in fuel costs, while rear-loading trucks were used to collect 3,244.88 tons and cost $30,010.42 in terms of fuel. This discrepancy suggests a difference in mileage between the front-loading and rear-loading fleets. The cost per hour to operate the front-loading trucks exceeds that of the rear-loading trucks despite the facts that the labor costs are uniform and fuel costs per ton collected appear to be lower for the front-loading trucks. Records provided by FOD suggest that this discrepancy arises from the fact that front-loading trucks cost more than rear-loading trucks. The purchase price for a rear-loading packer truck is estimated to be $170,000, while that of a front-loading truck is approximately $200,000. In addition, the front-loading truck is expected to have a higher depreciation rate per hour.

The total labor hours assigned to the rear-loading truck routes are also disproportionate in terms of tons collected; 8,736 hours were required to collect 3,244.88 short tons (0.3714 tons per hour). The front-loading truck fleet, in contrast, required 4,316 labor hours to collect 4,160.00 tons (0.9639 tons per hour).

It is anticipated that, because front-loading trucks are used primarily to collect mixed solid waste and rear-loading trucks are used to collect commingled recyclables, cardboard, and mixed solid waste, collection of recyclables introduces obstacles to efficiency. According to FOD records, of the total number of collection stops per week, 55% are for trash collection while 29% are for cardboard and 16% are for recycling (Redman 2008). This allocation of stops does not reflect the approximate waste stream composition, which is 79% trash, 8% cardboard, and 13% commingled recycling.

Front-loading trucks:
$20,052.66 (fuel) / 4,160.00 tons = ($4.82 (fuel)/ton)
($4.82 (fuel)/ton) / ($2.86/gal) = 1.69 gal/ton
(1.69 gal/ton) x (17.8 lbs CO_2/gal) = 30.1 lbs CO_2/ton = 0.0150 tons CO_2/ton collected
= 0.0150 $MTCO_2E$ / metric ton collected
= 0.0165 $MTCO_2E$ / short ton collected

Rear-loading trucks:
$30,010.42 (fuel) / 3,244.88 tons = ($9.25 (fuel)/ton)
($9.25 (fuel)/ton) / ($2.86/gal) = 3.23 gal/ton
(3.23 gal/ton) x (17.8 lbs CO_2/gal) = 57.5 lbs CO_2/ton = 0.0287 tons CO_2/ton collected
= 0.0287 $MTCO_2E$ / metric ton collected
= 0.0316 $MTCO_2E$ / short ton collected

The value calculated for rear-loading truck emissions per ton collected (0.0316 $MTCO_2E$ / short ton collected) is used for recycling and cardboard routes represented by arcs connecting input noted to allocation nodes. As with collection costs, a weighted average is used to calculate the average emissions per ton of trash collected. Because the organic waste is currently collected as part of the mixed solid waste stream, the same eco-impact value is used in the model.

4,160 tons (FL) + 1,716 tons (RL) = 5876 tons mixed solid waste
4,160 tons (FL) / 5876 tons = 70.80%
1,716 tons (RL) / 5876 tons = 29.20%
(0.2920 x 0.0287 tons CO_2/ton collected) + (0.7080 x 0.0150 tons CO_2/ton collected) = 0.0190 tons CO_2/ton collected
= 0.0190 $MTCO_2E$ / metric ton collected
= 0.0209 $MTCO_2E$ / short ton collected

EcoImpacts: Processes

The ecological impacts of landfilling and recycling are drawn from a lifecycle assessment of greenhouse gas (GHG) emissions and sinks associated with solid waste management published by the U.S. Environmental Protection Agency in 2006 (EPA 2006). Negative values indicate a net savings in GHG emissions. In the case of recycled materials, for instance, this accounts for process emissions, avoidance of virgin material harvest and processing, and avoidance of landfill emissions. Units are metric tons of CO_2 equivalent ($MTCO_2E$) per short ton of solid waste.

At this time, Ohio State essentially has three options for managing organic waste produced on campus. As suggested by the range of programs that are being implemented or considered by other universities at this time, these options include: continuing to collect organic waste along with mixed solid waste; composting; and anaerobic digestion. The first of these options, which is reflected by the current collection system, represents a number of missed opportunities. Clearly, including organic waste in the mixed solid waste stream means that landfill transport and tipping fees must be paid for each ton of organic waste. In addition, organic waste that is separated from other waste products has potential commodity values including fertilizer and fuel production.

The second option, composting, would allow waste processors to take advantage of the fertilizer produced and has been explored by FOD. While a number of OSU's benchmark institutions have initiated successful composting programs, it is not considered to be a viable option for the University at this time. According to OSU solid waste managers, accessible composting facilities are located in Delaware and South Charleston, Ohio, both of which are too far from campus to be cost-effective (Redman 2008; Dial 2008). The construction of a composting pad at Waterman Farm, an OSU facility located on Carmack Road, has been suggested as an alternative composting option. However, such an operation would require University vehicles, equipment, and staff, and would not be a self-sustaining program (Naumoff 2007).

The third option, anaerobic digestion, appears to be the most viable option for diverting Ohio State's organic waste from the landfill. Kurtz Brothers, Inc. plans to begin operating an anaerobic digester (AD) in 2009 at the Columbus Transformation Center adjacent to Columbus's former Waste To Energy Facility. The plant will be able to accommodate approximately 35,000 wet tons annually and is expected to accept waste deliveries six days per week (Kurtz, 2008).

Estimates based on past operations suggest that 0.5% of the outputs will be gaseous in nature and 10% will be in the form of topsoil amendments. Liquid residuals are also produced, and may be viewed either as a problem or an opportunity. According to Tom Kurtz, one objective of the project is to determine the best use of digestion byproducts; solids have the potential for use as soil amendments, while liquids contain nitrogen, ammonia, and potassium, and may also represent valuable opportunities (Kurtz, 2008). The remainder of the material sent to the AD facility is typically lost in evaporation during the digestion process.

It is anticipated that the Kurtz AD facility will consume less than 15% of the energy generated and has the potential to generate 500 kWh or more of surplus electricity (Kurtz, 2008). According to Tom Kurtz, biogas produced at the facility will be used in the most economically and ecologically efficient manner for that operation. In order to produce electricity, a generator would have to be placed on-site. Alternatively, the biogas could be sold to boiler gas (natural gas) consumers near the digester facility (Kurtz, 2008). Because natural gas consists primarily of methane, biogas may be used in its place, with the carbon dioxide component burning off. The digester itself will likely be operated using an on-site boiler or small generator to maintain the appropriate temperature (53-56^{o} C).

The advantages of anaerobic digestion are further amplified by the fact that the Kurtz digester is expected to have a higher loading rate than typical AD facilities. This implies that the facility can accommodate a higher proportion of solids relative to other operations, approximately 15-18%, and in effect requires that less infrastructure be developed and imposes a smaller "ecological footprint" (Kurtz, 2008).

Eco-impacts for anaerobic digestion, which is applied to organic waste, account for alternative energy production from biogas, as well as a transition to flatware, cups, and other disposable food packaging composed of bioplastic or other biodegradable materials. A 2006 report suggests that, accounting for both landfill diversion and energy production, approximately 1.1 $MTCO_2E$ is abated for each metric ton (1.0 $MTCO_2E$ per short ton) of food waste processed via anaerobic digestion (Levin 2006). In terms of energy produced with biogas at the facility, a more conservative estimate than those projected by the literature is applied to the Kurtz facility, which is projecting production of 40 kWh per ton of incoming, wet organic waste, or 200 kWh per dry ton. It is likely that additional generation will be possible, but current estimates are used for this analysis.

A 2007 lifecycle analysis (LCA) of carry-out and dine-in meals produced at the North Commons dining facility further supports the transition to biodegradable food service packaging, even in the absence of composting or anaerobic digestion systems. Carry-out meals are typically packaged in Styrofoam and plastic containers and accompanied by traditional plastic utensils and a plastic bag. This disposable, non-biodegradable packaging is largely responsible for the meals' negative environmental impacts, which are found to far exceed those of dine-in meals. While bioplastic-packaged takeout meals do not reflect those consumed from reusable dinnerware, they are expected to reduce the "ecological footprint" of carryout food. According to this LCA, each Styrofoam entrée box emits 1.818 g carbon monoxide (CO) and is responsible for nearly half of the carbon dioxide (CO_2) emissions produced by a takeout meal (Reithman, 2007). Plastic is also found to contribute significantly to the greenhouse gas emissions associated with the lifecycle of these packaged meals.

The use of plant-based plastics contributes to emissions reduction by reducing the quantity of plastic and other non-biodegradables sent to the landfill, as well as reducing the ecological impacts associated with initial production. A lifecycle analysis comparing the bioplastic poly-β-hydroxybutyric acid (PHB) with polypropylene (PP; #5 resin code) and high and low density polyethylene (HDPE, LDPE; #2 and #4 resin codes, respectively) found that PHB produced 1.960 MTCO$_2$E per metric ton produced (1.779 MTCO$_2$E per short ton), while PP produced 3.530 MTCO$_2$E (3.203 MTCO$_2$E per short ton) and PE produced between 2.510 and 3.040 MTCO$_2$E (2.278-2.758 MTCO$_2$E per short ton) (Harding et al., 2007). A comparison of polylactic acids (PLA), PP, and HDPE found that greenhouse gas emissions, in terms of CO_2 equivalents, are 50% higher for PP and 75% higher for HDPE compared with PLA (Butler, 2007). It is estimated that polystyrene (PS; #6 resin code) emits 4.330 MTCO$_2$E metric ton produced (3.929 MTCO$_2$E per short ton) (Zentner & Lieb, 2007). Polypropylene and polystyrene are typically used to make plastic flatware, while foam containers for hot food are generally made of polystyrene.

	Landfilling	Recycling	Anaerobic Digestion
Mixed Solid Waste	0.42 MTCO$_2$E/ton 0.46 MTCO$_2$E/MT	N/A	N/A
Cardboard	0.40 MTCO$_2$E/ton 0.44 MTCO$_2$E/MT	-3.11 MTCO$_2$E/ton -3.43 MTCO$_2$E/MT	N/A
Mixed Paper	0.35 MTCO$_2$E/ton 0.39 MTCO$_2$E/MT	-3.54 MTCO$_2$E/ton -3.90 MTCO$_2$E/MT	N/A
Plastic	0.04 MTCO$_2$E/ton 0.04$_4$ MTCO$_2$E/MT	-1.49 MTCO$_2$E/ton -1.64 MTCO$_2$E/MT	N/A
Aluminum	0.04 MTCO$_2$E/ton 0.04$_4$ MTCO$_2$E/MT	-13.57 MTCO$_2$E/ton -14.95 MTCO$_2$E/MT	N/A
Other metals	0.04 MTCO$_2$E/ton 0.04$_4$ MTCO$_2$E/MT	-5.25 MTCO$_2$E/ton -5.79 MTCO$_2$E/MT	N/A

Organic (Food scraps)	0.72 $MTCO_2E$/ton 0.79 $MTCO_2E$/MT	N/A	1.0 $MTCO_2E$/ton 1.1 $MTCO_2E$/MT

Table 3. Greenhouse gas emissions associated with waste disposal processes (EPA 2006).

Volume to Mass Conversion for Biogas Components:

The proportion of CO_2 and CH_4 in biogas produced by AD is found to remain relatively consistent under varying conditions, while the total quantity of biogas produced depends upon the substrate used (Reith et al., 2003). The literature suggests that biogas produced by anaerobic digestion of food waste is composed of approximately 73% methane (CH_4) and 27% carbon dioxide (CO_2) by volume (Zhang et al., 2007). These values are converted to metric tons using molecular weights and the ideal gas law. Clearly, because real gases diverge from ideal behavior, these calculations provide approximations.

$PV_{CH4} = n_{CH4}RT$ $\qquad$ $PV_{CO2} = n_{CO2}RT$

$n_{CH4} / V_{CH4} = n_{CO2} / V_{CO2}$ $\qquad$ $n_{CH4} / (73\%\ v/v) = n_{CO2} / (27\%\ v/v)$

$n_{CH4} = 2.7037\ n_{CO2}$

CH_4: 16.0425 g/mol $\qquad$ CO_2: 44.0095 g/mol

2.7037 x 16.0425 g = 43.3741 g $\qquad$ $CH_4 : CO_2$ (mass) = 43.3741 : 44.0095 = 0.4964 : 0.5036

Institutional Analysis

This analysis includes a range of factors that have the potential to influence the implementation of sustainable practices, including solid waste management, at colleges and universities. Variables and trends of interest include changes in recycling rates over the past ten years, types of recycling systems in place, student engagement, facilitators and obstacles to "greening" waste management, and exploration of innovative practices.

Characterizing College and University Recycling Programs

Survey participants include waste managers at institutions considered to be Ohio State's benchmarks. The majority of respondents held titles explicitly related to recycling, such as "recycling coordinator," with the remainder of titles including the terms sustainability, waste management, or administration. Most (75%) participants were either relatively new to their position, having held it for three or fewer years, or had held their position for more than a decade. For the most part, those who had held their positions for at least ten years (20.3 years on average) had titles suggesting responsibility for solid waste management but omitting the term recycling. This could be attributable to the more recent emergence of university sustainability and integrated waste management programs, many of which have been placed under the umbrella of other physical facilities programs.

As anticipated, most respondents described an increase in container recycling rates over the past ten years. Of the twelve universities included in the survey, only one experienced a decline in recycling rates between ten and five years ago and two remained static. However, from five years ago to present, three schools' rates declined, while two remained the same.

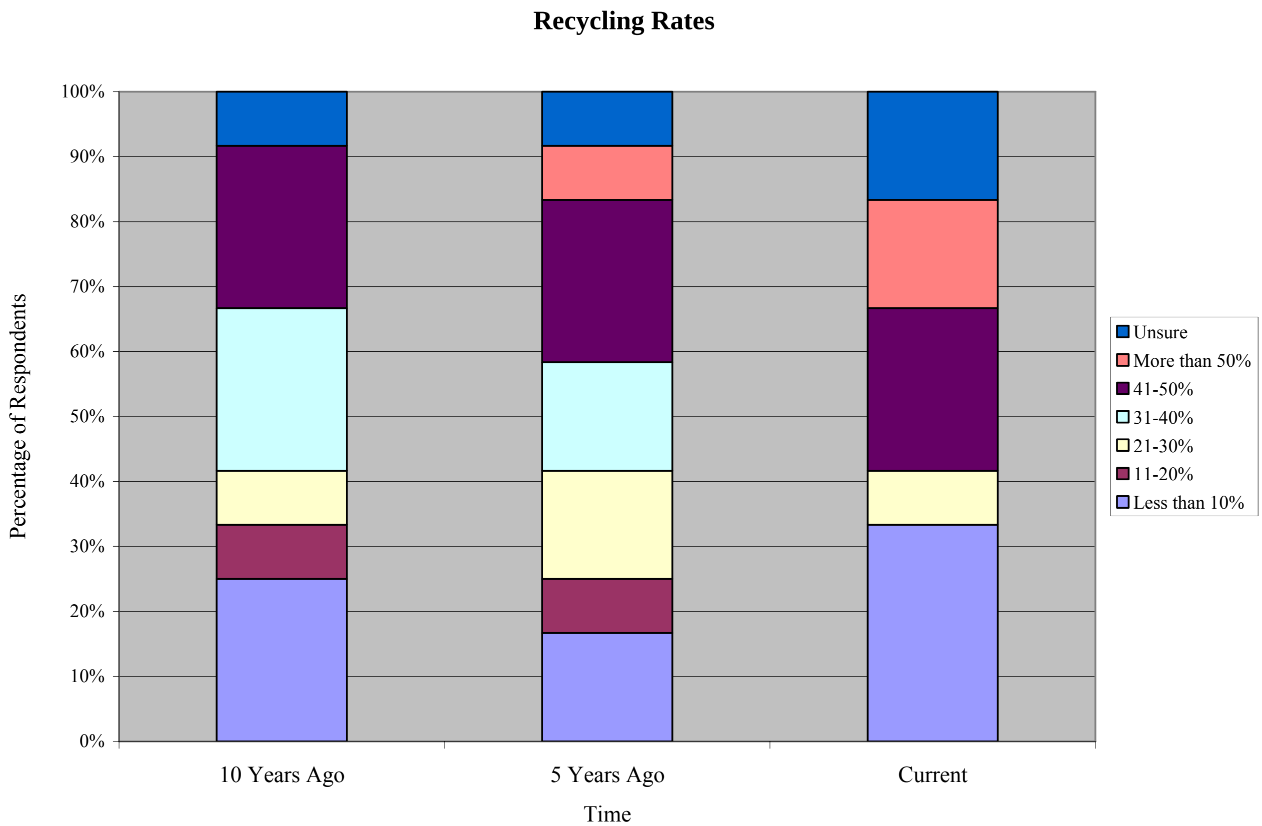

Figure 2. Recycling rates at participating institutions over the past 10 years.

While individual schools' recycling rates and trends vary, nearly all participants responded positively when asked if their respective departments are currently working to increase container recycling rates. The most common method for achieving this goal appears to be improving the accessibility, convenience and visibility of on-campus recycling. The introduction of recycling containers and facilities into more classroom and academic buildings is among the most frequently cited strategies. Residence halls and other university facilities, such as conference centers, are also being targeted through the addition of recycling containers and educational campaigns. Finally, sporting events are mentioned as opportunities for expanding collection.

Along with augmenting physical infrastructure and improving access to recycling bins, participants cited awareness campaigns as part of their efforts to increase recycling. Outreach methods designed to reach students and inform them of recycling opportunities on campus include e-mails, flyers, and explanatory labeling on recycling bins. One participant described student education campaigns as efforts to “create a culture of recycling and sustainability,” a sentiment captured by several participants. Finally, establishing partnerships, including adding collection staff, collaborating with housekeeping employees, and seeking state grants facilitates collection and increases capacity.

Respondents described efforts to increase not only the quantity, but also the variety of materials recycled. Construction and debris (C&D) waste and organic waste are common elements of growing recycling programs. Electronics and packaging are also mentioned as products that have recently been integrated into university recycling programs. Respondents noted that efforts to make recycling programs more comprehensive in the future are likely to include transitions toward reuse-focused programs and commingled collection.

Currently, commingled (single-stream) recycling systems seem to be rare among OSU’s benchmarks. One participant reported introducing a commingled recycling program in residence halls but not elsewhere on campus, and all other respondents described source-separated systems. Marketability of separated materials is cited as a reason for avoiding commingled collection, and nearly all respondents collect payment for recyclables. At least half of the institutions surveyed receive payment for cardboard (67%), aluminum (50%), other metals (58%), and paper (67%). Other materials for which participating institutions receive payment include ink cartridges, cell phones, plastics, and electronics. Despite commodity values, some respondents noted the potential for a transition to commingled collection in the future.

Student Involvement

Student activity is often cited as a key element of successful sustainability programs at colleges and universities. Survey responses reflect this trend, with most (83%) participants stating that student activity had influenced waste management practices at their respective institutions. In some cases, those who did not feel that students had exerted much influence at present suggested that emerging student movements are likely to produce change in the near future. Upon being asked to identify student activities that have contributed (or are expected to contribute) to advances in sustainable waste management practices, the majority (58%) of respondents selected all of the following: student organization(s) focused on recycling specifically; student organization(s) focused on general environmental awareness; student government; and students enrolled in a related course or academic program. Some participants cited one or two of these student activities, along with other student roles, such as student involvement in hands-on processes at recycling facilities and recycling-oriented community service programs.

A variety of extracurricular and educational programs related to recycling, including academic programs, are described. At the University of Washington, for instance, an undergraduate student organization campaigned for recycling and composting in the residence halls while the University's forestry students initiated an electronics recycling program that is operated by the University's recycling program. Coursework also integrates sustainability at UW, and seniors have the option of completing capstone projects on campus environmental issues (Elko, 2008). Other respondents describe student demand for recycling as the catalyst for university recycling programs, student fees' contributions to recycling operations, and the inclusion of student employees in recycling and related education programs.

When asked about recycling and sustainability education programs and their impact, most (58%) respondents stated that action had been taken and had produced *some* measurable, positive change or *significant*, positive change. Environmental studies curricula, sustainability courses in various academic departments, internships with recycling coordinators, and collaborative conservation efforts between students and administration are among the programs cited. Some institutions reported the establishment of courses organized by students interested in expanding environmental education, and the University of Washington has begun an initiative to create a College of the Environment (UW, 2007; Elko, 2008).

Facilitators and Obstacles to Sustainable Operations

Respondents were asked to rank five factors that are often associated with the success of recycling programs to indicate which options they consider to be the most significant facilitators for the implementation of container recycling practices and policies at their institutions. Options include: support from administration; support from faculty and/or staff; support from students; financial support (grants, etc.); and other. Responses suggest that support from administration is viewed as the most important facilitator to recycling efforts, followed by support from students, support from faculty and staff, and financial support. Some participants pointed out that these factors are interrelated and, as a result, somewhat difficult to rank. It was noted, for instance, that administrative support is typically accompanied by financial support but is of little use without staff implementation and student participation. The integration of one or more of the types of support listed, as in the collaboration between students and staff for example, is also cited as being more important than the individual facilitators. Conversely, competing interests and conflict between the various sources of support is mentioned as a potential challenge; in other words, legitimate collaboration must be fostered.

Respondents were also asked to rank five factors to indicate which options they consider to be the most significant obstacles to institutionalizing recycling practices. Options include: lack of administrative interest and/or support; lack of student interest; infrastructure constraints; financial constraints; and other. Responses suggest that infrastructure constraints are viewed as the most important obstacle, followed by financial constraints, lack of administrative support, and lack of student interest. One respondent noted that lack of administrative support was particularly damaging because student programs and support, even when strong, are not consistent enough to sustain and advance an entire university recycling program.

Like support from various stakeholder groups, university policies and their impact on the implementation of sustainable, integrated waste management practices are gauged by this survey. When asked whether institutional policies have served to promote sustainable solid waste programs, participants were evenly divided between positive and negative responses. Responses to a question about policies that have hindered the implementation of sustainable solid waste management practices were similarly divided, and were largely peripheral to recycling operations despite their impact on these operations. For instance, decentralized purchasing is cited as an obstacle to the adoption of green purchasing practices, as are budgetary constraints and unionized staff. In some cases, fire codes prevent the placement of recycling bins in high-traffic areas, and attempts to improve convenience to students in dining halls and other facilities promotes the use of disposable items. Public universities are typically constrained in terms of their financial operations and property management. As one survey respondent pointed out, strict accounting systems often require that reusable items be sold rather than given away, and those which are not sold must be disposed of, typically at a landfill.

Some policies affecting solid waste management are well-intentioned but may be relatively neutral in their impact; for instance, some institutions have established policies that encourage but do not mandate recycling. Others, however, are quite specific; institutions characterized by such policies include the University of Washington (UW), the University of Kansas (KU)[7], and the University of California (UC) system. At UW, it is noteworthy that state, county, and city regulations are applicable to the University's operations. In 2005, the City of Seattle introduced an ordinance that prohibits the disposal of significant (10% by volume) amounts of paper, cardboard, and yard debris in garbage, and enforces the rule with fines (City of Seattle, 2004). The ordinance required that the University engage students and other groups in recycling efforts, as a waste characterization study conducted at UW in 2004 suggested that 39% of its landfill waste was recyclable paper (UW, 2008). In addition, UW's President has signed on to the American College & University President's Climate Commitment (ACUPCC), for which the University must complete an emissions inventory, develop a plan of action directed toward carbon neutrality, and integrate sustainability into curricula. The University has also established an Environmental Stewardship Advisory Committee (ESAC) to guide administrators in pursuing the objectives outlined in the UW Environmental Stewardship Policy Statement. Between 2006 and 2007,

[7] KU does not currently have a system in place to enforce the University's recycling mandate, but the Provost's Environmental Policy states that all students and employees are expected to observe and participate in campus conservation efforts (Hoins, 2008).

UW established a green fleet (automobiles), introduced compact fluorescent lightbulbs in housing and food services buildings, and established a plan to transition to 100% recycled paper for the University's publication services (ESAC, 2007). The University has also developed a green cleaning policy for its custodial services along with integrated pest management for landscaping.

New Directions: Organic Waste, Energy Conservation, and Sustainable Purchasing

Survey participants were asked about specific, emerging solid waste management and sustainability practices, including composting, energy conservation, and sustainable purchasing. At Ohio State, interest in each of these possibilities has been expressed, and their implementation at benchmark institutions suggests that they represent promising options for OSU.

When asked about the degree to which their departments or institutions had explored composting food wastes, the majority (58%) of respondents suggested that action had been taken and had produced either *some* measurable, positive change or *significant*, positive change, while 25% stated that composting had been considered but no action had been taken. Several institutions have introduced pre- and post-consumer composting programs at dining facilities, coffee shops, and other campus facilities, reporting compost rates ranging from around 300 to 2000 tons annually. Interest in starting composting systems in the near future is also expressed in some cases. One institution had previously composted a small portion of its organic waste, but had eliminated the program, while another operated a worm composting system, which is difficult to maintain when students are absent during breaks. Another university implemented pilot composting programs but did not establish a structured system, although graduate research is currently focused on developing a new program. Undergraduate students have also been engaged in on-campus composting programs, while institutions near compost facilities, in some cases, report sending organics from dining halls to these sites. Respondents described several challenges, including cockroach and rodent infestations, regulations barring on-site composting, and distance of composting facilities, a challenge that has also been identified by OSU.

Along with waste diversion, respondents were asked for information on the degree to which their respective institutions had explored energy conservation practices. Results suggest that significant progress is being made in this area, as all respondents stated that some type of action had been taken, with 67% noting a *significant*, positive change and 25% identifying *some* measurable, positive change. Respondents described programs including "lights out" campaigns, LEED certification of new and remodeled buildings, power plant modifications such as new boilers that increase energy efficiency, elimination of coal-based operations, and the purchase of wind energy. The introduction of action-sensitive lighting, replacement of outdated equipment, and the substitution of compact fluorescent lightbulbs for incandescent bulbs are also listed among energy conservation initiatives.

Some respondents also described the expansion of certain stakeholders' roles as a central element of energy conservation advances. Establishment and expansion of sustainability offices, along with the active involvement of students in university energy awareness campaigns, is considered an important element of progress. Partnerships with outside organizations have also allowed for the expansion of energy efficiency programs. The University of Kansas for instance, participates in energy performance contracting as permitted by House Bill 2603 and partners with Chevron Energy Solutions to install energy and water saving technologies. Among these technologies are upgraded lighting, improved systems for steam and electrical distribution, a new steam boiler, window tinting, and low-flow restroom fixtures (KU Facilties Operation, 2008). In addition, two Chevron employees work full-time as energy resource managers (ERM) at KU and assist University staff with continuing conservation efforts. A number of University policies related to energy efficiency complement this program, including specific guidelines on the management of buildings, new construction, lighting, heating, cooling, water usage, transportation, purchasing and recycling (KU Office of the Provost, 2008).

The University of California system has also benefited from partnerships with external organizations, particularly the Alliance to Save Energy (ASE) and its Green Campus program. The University of California (UC) and California State University (CSU) campuses currently involved in the program include: Humboldt State University, Cal Poly San Luis Obispo, CSU Chico, UC Berkeley, UC Santa Barbara, CSU San Bernardino, UC Irvine, UC Merced, UC San Diego, UC Santa Cruz, San Diego State University, Cal Poly Pomona, and Stanford University (ASE, 2008). ASE provides funds for student interns to conduct retrofits, distribute compact fluorescent lightbulbs, and develop other projects to improve energy efficiency and awareness at their institutions. Additional opportunities and incentives are available through Southern California Edison (SCE), which has allowed UC Santa Barbara to improve energy efficiency while reducing costs. The University participates in SCE's Standard Performance Contract, which provides incentives to offset the cost of installing energy efficient infrastructure (SCE, 2008), as well as the statewide UC/CSU/IOU (University of California, California State University, and Investor-Owned Utility) Energy Efficiency Partnership Program, which supports energy efficiency retrofits, monitoring based commissioning, technology demonstrations, and training and education. As a result, UCSB has installed approximately 450 restroom occupancy sensors, retrofitted traffic signals with light-emitting diodes (LEDs), and commissioned a campus central plant chilled water system (Higher Education Energy Partnership, 2007).

In addition to solid waste diversion and energy conservation, participants were asked about the degree to which their departments or institutions have considered sustainable purchasing practices or policies. Overall, responses suggest that more progress has been observed in solid waste diversion and energy efficiency improvements than in sustainable purchasing efforts. Most respondents (67%) stated that action had been taken and either had *not yet* produced measurable change or had produced *some* measurable, positive change. The remaining responses were divided equally between those who given no consideration to sustainable purchasing practices and, contrastingly, those who had noted action accompanied by *significant*, positive change. The institutions at which positive change was found to result from sustainable purchasing practices vary in the degree to which they regulate purchasing through policy. In some cases, acquisition of recycled-content products is simply encouraged, while in others purchasing departments promote recycled-content products and sustainable practices affect business contract decisions. The University of California sustainability policy, for instance, includes a purchasing section that mandates acquisition of 30% post-consumer content paper and seeks to reduce ecological impacts associated with purchasing by reducing packaging waste and establishing strategic sourcing teams. The system includes a point system for contracts in which points are given to vendors for sustainable practices such as take-back programs for packaging and recyclable products, and points are advantageous to vendors in the RFP process.

Respondents who noted that either no action had been taken or no measurable progress had been made described challenges largely associated with decentralization and ambiguity. For instance, one participant noted that their institution purchased office supplies from a vendor that offers “green” products, but had no way of determining whether staff were purchasing these items. Defining “sustainable purchasing” practices is also a challenge, as are enforcing policies and measuring change, particularly when numerous departments are responsible for purchasing. Despite these challenges, some of these respondents suggested that developing sustainable purchasing programs is among their institutions’ current areas of progress or objectives.

Results

Economic Analysis

Financial Impacts

The most basic intent of the model is to establish a base case reflective of the data already maintained by FOD in order to demonstrate its utility for examining possible alternatives. When cardboard, recycling, and mixed solid waste systems are isolated, each system included in the model appears to reflect current data, as does the system’s overall cost.

The model suggests that, at this time, diverting organic waste to an anaerobic digestion facility provides no financial benefit to the University. The model estimates the total cost of the university’s solid waste system, including commingled recycling, cardboard, organic waste, and mixed solid waste, is $1.2 million ($1,207,978.38), which reflects the value suggested by FOD data ($1,205,698.00). Introducing anaerobic digestion for all organic waste into this system would raise this figure to $1,564,264.96. The discrepancy between these costs is attributable primarily to the expense associated with biodegradable food packaging. If the cost of bioplastics were equal to that of traditional materials used for food packaging on campus, making use of the AD facility would save money. In this case, the total cost is $1,176,862.83. The tipping fee for the Kurtz AD facility is expected, initially, to reflect the landfill tipping fee. As the model is currently structured, organic wastes bypass the transfer station, avoiding the associated fees. If organic waste is not delivered to the digester by University vehicles, or if third parties are needed for any reason, additional costs would be expected. Conversely, AD tipping fees are expected to decline as the profitability of biogas and organic solids begins to offset the cost of operation.

The model also suggests that recycling saves the University a substantial amount of money despite the higher collection costs. When the option to recycle commingled materials and cardboard is removed, the cost of the system is $1,234,885.94. The savings attributed to recycling, however, appears to be primarily associated with the commodity value of cardboard, as the system cost is $1,207,837.31 when the option to recycle commingled materials is removed but cardboard recycling is not.

Decision Diagram: Impact of Bioplastic Prices

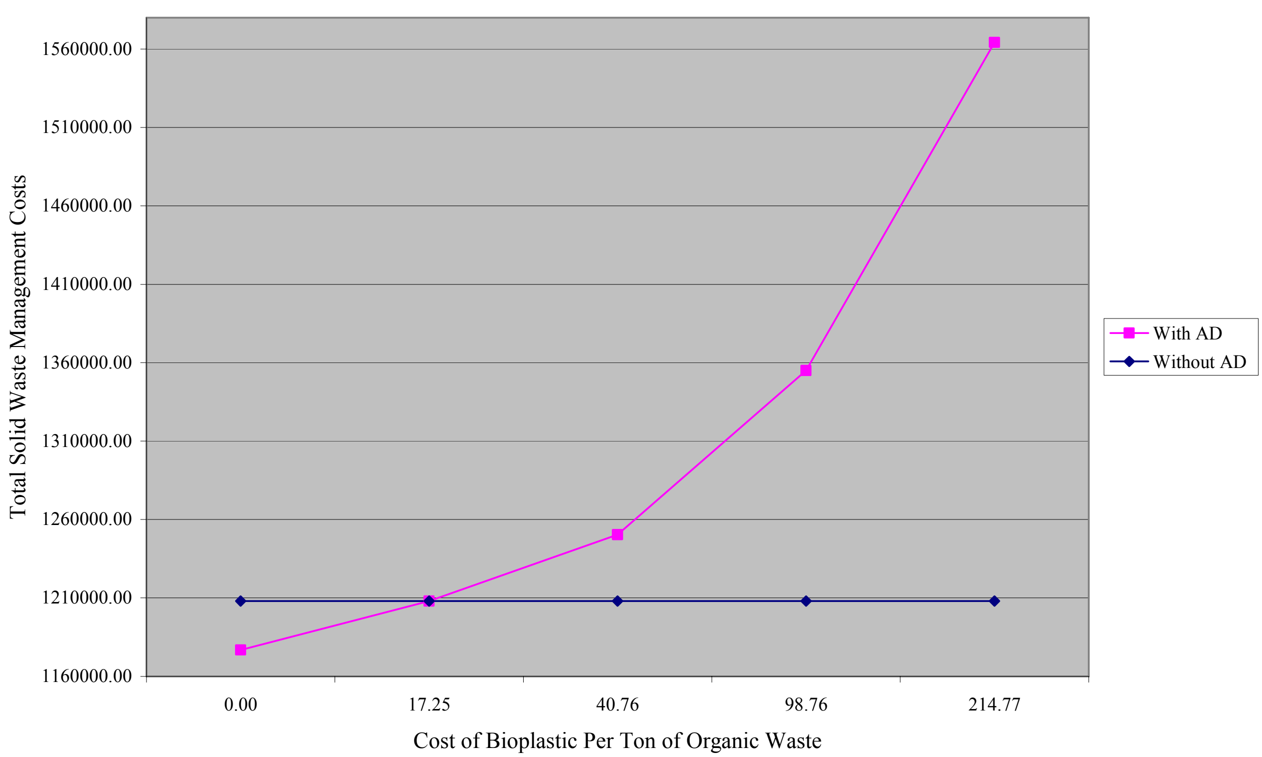

Figure 3. Decision Diagram illustrating the "break-even" point at which the cost of biodegradable packaging and utensils per ton of organic waste makes anaerobic digestion a financially viable option. At

$17.25 per ton of organic waste, total solid waste management costs are equivalent for systems with and without anaerobic digestion.

Ecological Impacts

Eco-impacts are measured in terms of $MTCO_2E$ per short ton of solid waste. Both recycling and anaerobic digestion are found to contribute significantly to reducing greenhouse gas emissions. Commingled recycling is found to save 3,550.53 $MTCO_2E$ annually, while cardboard recycling saves 2,270.82 $MTCO_2E$ and results suggest that anaerobic digestion has the potential to save another 3,102.54 $MTCO_2E$.

	Mixed Solid Waste (Trash)	Commingled Recycling	Cardboard Recycling	Anaerobic Digestion
FOD Records	$782,804.36	$169,374.18	$253,519.46	N/A
Model	$785,077.40	$169,375.40	$253,525.59	$356,286.58
EcoImpact ($MTCO_2E$) per $ Invested	0.00485347 $MTCO_2E$ / $	-0.0209624 $MTCO_2E$ / $	-0.00895697 $MTCO_2E$ / $	-0.00870799 $MTCO_2E$ / $

Table 4. Comparison of model results with FOD data and emissions reduction costs.

Institutional Analysis

Trends

A number of trends are identified among the benchmark institutions included in the survey data. While it is clear that every institution is experiencing a unique set of successes and challenges, seven clear trends are identified:

1. Dissatisfaction with the status quo: Efforts are underway at nearly all of the institutions included in the survey to increase container recycling rates. Beyond working to increase the quantity of waste diverted from the landfill, many of OSU's benchmarks are working to integrate new practices – such as electronics recycling and composting – into their waste management systems. In addition, most respondents had explored food waste diversion options, with composting being the most common, and had realized measurable, positive change.

2. Financial constraints: Despite widespread efforts to improve upon the status quo, budgetary restrictions have introduced barriers to certain transitions. Commingled systems, for instance, are rare and few participants expressed intentions of adopting single-stream recycling methods. Commodity values of recycled products are frequently cited as the reason for this reluctance.

3. Student engagement: The most commonly noted effort intended to improve recycling rates and sustainable practices in general is improving access to and awareness about recycling opportunities on campus. Recycling containers are becoming more commonplace as well as more visible, and universities are experiencing a corresponding increase in recycling rates. Student organizations focused on recycling or environmental awareness, student government, and students enrolled in related academic programs are all believed to have contributed significantly to progress, according to the majority of respondents. Recycling and sustainability education programs, in most cases, received support from students and produced measurable, positive change.

4. Administrative support: Support from administration is considered to be the most important facilitator to recycling efforts. While respondents generally felt that student support was a valuable tool in promoting sustainable practices, administrative support provides the consistency necessary to operate a successful recycling program. In addition, administrative support is often accompanied by financial support. Respondents reinforce the assertion put forth by Bekessy et al. (2007) that depending on bottom-up approaches alone will not yield measurable improvement.

5. Stakeholder collaboration: When ranking facilitators and obstacles to sustainable practices, it was often noted that stakeholders' roles are intertwined, and that partnerships are essential to progress. This includes not only students, staff, and administration, but also local communities and private organizations.

6. Clear statement of and commitment to sustainability objectives: When asked about university policies and their impact on recycling and sustainability initiatives, responses were evenly divided. However, the importance of having specific policies in place is often noted, as suggested by Allwright et al. (2000). Ambiguity in policy, along with decentralized purchasing and record keeping, are cited as obstacles to the adoption of sustainable purchasing practices. Dependence upon qualitative rather than quantitative objectives, omission of accountability and monitoring mechanisms, and abstract policy statements, as anticipated, tend to hinder progress (Dahle & Neumayer, 2001).

7. Energy conservation as a priority: Among the sustainability efforts included in the survey, respondents express the greatest sense of accomplishment in energy conservation, with most noting significant, positive change. Related programs vary widely, with some respondents

discussing the installation of compact fluorescent lightbulbs and others highlighting the replacement of boilers, heating and cooling systems, and other large-scale infrastructure.

Discussion

Economic Analysis: Balancing Ecology and Economy

The “zero waste” goal, which proposes that resources be viewed as part of a “cradle to cradle” rather than “cradle to grave” system, has become increasingly common among U.S. colleges. Ohio State’s current recycling system has brought the University somewhat closer to this goal, as shown by the greenhouse gas savings suggested by the model. However, it is clear that significant changes will have to be made if OSU is to minimize its ecological footprint. The introduction of commingled recycling is among current efforts to increase campus recycling, and FOD is working to achieve the goal of 30% waste diversion. Organic wastes represent an opportunity for the University to transform students’ trash into treasure – a source of bio-fuel in a time of soaring petroleum prices and global climate change. While obstacles to composting have already been identified, the potential for anaerobic digestion to help lead OSU toward zero waste cannot be overlooked. The model suggests that, economically, anaerobic treatment is very costly relative to the landfill option currently used for organics and other mixed solid waste. However, economic and ecological shifts are likely to make this an increasingly realistic option.

As fuel prices rise, the value of methane generated via anaerobic digestion is also likely to rise. Because the objectives of the Kurtz facility are twofold – to promote sustainable waste management while remaining financially viable – it is anticipated that as commodity values for AD outputs rise, tipping fees will decline. Declining fees for the process itself are likely to be accompanied by lower bio-packaging prices as the market for biodegradable products expands and the cost of producing petroleum-based plastics increases. This market has expanded notably in recent years and is expected to continue to grow.

Despite the growth of the bio-plastics industry, concerns have been expressed about the consistent availability of food packaging in the large quantities required by Ohio State. However, the adoption of biodegradable packaging by large universities and businesses, including the University of Washington and Wild Oats Markets, among others, suggests that production is meeting demand at this time.

Clearly, budgetary constraints cannot be ignored in the design of waste management systems, but the relative ecological impacts of the options considered here should be given some consideration. The potential greenhouse gas savings associated with diverting organic waste to an anaerobic digester, 3,102.54 $MTCO_2E$ per year, implies a considerable opportunity for reducing the University’s ecological footprint. The educational value of sustainability programs at universities is also noteworthy; the “Scarlet, Gray & Green” message is of little value if students are not encouraged to adopt sustainable practices in their daily lives and watch the University do the same. Simple marketing efforts, such as the placement of biodiesel labels on campus buses and signage on recycling trucks, have the potential to raise awareness among students.

Shortcomings of the model must also be considered. Among these is the diversion of paper and cardboard, both of which can be processed with anaerobic digestion but are excluded from the incoming waste stream. Because cardboard has a substantial commodity value, it is unlikely that it would be worthwhile to process it differently. Similarly, paper is currently recycled by Rumpke at a lower per-ton cost than the projected digester rate.

Past work also suggests that eco-impact estimates may be somewhat high, although they are based on EPA data. Ovuworie (2008) estimates that in 2006, solid waste accounted for 2,568 $MTCO_2E$ at OSU, and between 2002 and 2006 the highest annual estimate is 3,368 $MTCO_2E$. The results of the model attribute GHG savings exceeding these figures to certain waste management options.

Most of the challenges encountered while developing the model are related to data availability. Calculations are founded largely upon estimates, and it has been suggested that the quantity of available organic waste is insufficient to deem an alternative management system cost-effective. Conducting waste audits would provide more reliable information, as would including all campus buildings in related analyses. A waste characterization study conducted at the University of Michigan, for instance, includes student unions, which will be an important consideration when the Ohio Union is reopened. Similarly, a University of Washington study includes art buildings, outdoor trashcans, and other, more specific waste sources. Progress is being made toward improved monitoring and metrics for waste management at Ohio State, and data collected in the future is expected to permit a more accurate characterization of the University's solid waste.

Institutional Analysis: Lessons and Recommendations

The trends identified among Ohio State's benchmark institutions, particularly those that have made notable progress toward integrated waste management and sustainable operations in general, suggest a number of recommendations for OSU. Collaboration, purchasing, and solid waste management are among the areas in which OSU has the potential to improve.

Collaboration and partnerships were frequently cited as essential elements of progress toward sustainable practices at the universities included in this study. In recent years, Ohio State has taken steps in the right direction by bringing together students, faculty, and administration through the recently established Recycled Paper Task Force, LEED (Leadership in Energy and Environmental Design) building policy, and CampUShed forum. The Ohio Department of Natural Resources has also become involved, provided support for academic endeavors focused on sustainability. Based on survey responses, it appears that potential exists for significant improvement in both professional development and academic programming. For instance, respondents cited student internships with recycling coordinators and other university sustainability staff as a valuable method for both furthering the programs' success and aligning the efforts of students and staff toward a common objective. It was noted that student interns not only contributed time and interest, but also valuable suggestions and ideas. Similarly, the work of student organizations is often a valuable first step, but support from staff and administration is considered to be essential to successful sustainability initiatives. Sustainability-oriented courses and research programs, like student internships, are cited as opportunities to engage both students and faculty. Survey respondents described capstone courses focused on sustainability, along with related academic majors, minors, and concentrations. Ohio State's College of Food, Agricultural, and Environmental Science (CFAES), particularly the School of Environment and Natural Resources, offers a variety of course on environmental science, policy, and management. The College of Engineering has also introduced relevant courses and research opportunities, and the College of Business has introduced one green business course. However, students outside of CFAES are not typically exposed to sustainability concepts in the classroom. Capstone courses, which are required for all undergraduate students at OSU, represent an opportunity to introduce additional environmentally focused classes. The revision of the University's general education requirements (GEC) also represents a possible vehicle for introducing such coursework, particularly through new programs such as the "freshman cluster," a three-course sequence designed to expose students to a particular topic for more than a single quarter.

Among the systems that have already been influenced by student-administration collaboration at OSU is purchasing. While it may seem intuitive that a transition to sustainable practices at the university level introduces complexity to operations, it is in fact eliminating "red tape" that appears to be essential to environmentally responsible purchasing practices. Purchasing is closely associated with the importance of both explicit policy and transparency. It is difficult to mandate that all office paper have a particular recycled content value, for instance, if university departments are free to establish their own contracts. Decentralized purchasing also introduces challenges related to metrics, as surveys suggest; using the same example, it would be difficult to gauge the total quantity of office paper consumed on campus under a decentralized system.

Centralized purchasing contributes to monitoring and accountability, which are also found to be among the essential elements of progress toward sustainability. Promoting sustainability among the various campus stakeholder groups and encouraging positive change requires that they be aware of their consumption and that progress be measurable. Ohio State has begun energy audit pilot programs isolated to a few campus buildings, and plans for additional studies are in place, although budget and infrastructure remain hindrances. The University of California at Santa Barbara represents what might be OSU's ultimate goal in terms of energy monitoring; a centralized system is used to measure consumption of individual buildings and a University website dedicated solely to energy provides the energy consumption for each building in real time. This type of information allows for facilities managers to identify the most consumptive buildings and tailor conservation efforts and capital investments accordingly. It also serves as an educational tool and allows for the identification of consumption trends. The benefits of such a monitoring system – and the investment required for its implementation – highlight the frequently mentioned focus on energy conservation and underscore the benefits of establishing partnerships. Involvement with the Green Campus program sponsored by the Alliance to Save Energy (ASE) has provided UCSB with the resources necessary for certain advances in energy conservation and awareness. This success suggests that it is worthwhile to seek partnerships with businesses and organizations outside of the university to provide both technical and financial support.

Results also imply that, like energy, solid waste is an area in which there are lessons to be learned from other institutions. Nearly all of the institutions surveyed are participating in some sort of organic waste diversion program, typically composting at various scales. As discussed, composting facilities are not yet accessible to Ohio State due to distance, and anaerobic digestion (AD) appears too costly. However, it is the cost of biodegradable flatware and packaging alone that make AD a financially unrealistic option at this time, but market growth, to which OSU has the potential to contribute, is likely to lower the price discrepancy. Making use of an AD facility represents an opportunity for the University to decrease its greenhouse gas emissions, as illustrated by the model. Further, while the balance between financial and ecological concerns is central to this analysis, educational benefits should not be ignored. Many survey participants noted some level of student involvement in composting programs, with responsibilities ranging from organic waste collection to related research projects. Establishing an alternative organic waste management system could provide opportunities to further engage students in the broader mission of creating a sustainable campus.

While the institutional analysis provides a number of insights into the implementation of sustainable practices in higher education, several shortcomings of the survey instrument and available information must be considered. First, responses suggest that ambiguities in certain questions may have introduced some inconsistency. For instance, questions requesting that participants rank certain facilitators and obstacles were treated, by one respondent, as Likert scale questions. The term "container recycling" also drew inquiries, and should have been more clearly defined in the survey itself. Organic waste, on the other hand, should have been addressed in broader terms. While composting is addressed, additional questions related to anaerobic digestion and other organic waste treatment options should have been included. Finally, in some cases records with certain pieces of data, such as recycling rates during a specific time period, were not available to participants; consequently, some were unable to respond to all questions. It is likely that administering a pre-test, which was omitted due to time constraints, would have revealed some of these challenges earlier in the survey process.

Conclusion

Both survey data and model results suggest that there is a great deal of progress to be made in terms of "green" practices at Ohio State. Advances that have been made at the University's benchmark institutions suggests a number of ways that OSU can promote sustainability by better engaging students, promoting collaboration, and monitoring energy consumption and waste production. The EcoFlow^{TM} network demonstrates the ecological and economic benefits of recycling programs already in place at OSU and, like survey data, suggests that organic waste diversion may be among the University's best options for reducing its ecological footprint. Finally, this project illustrates the importance of integrating qualitative and quantitative measures of sustainability to create a more complete picture of the progress that has been made and the potential impacts of future advances.

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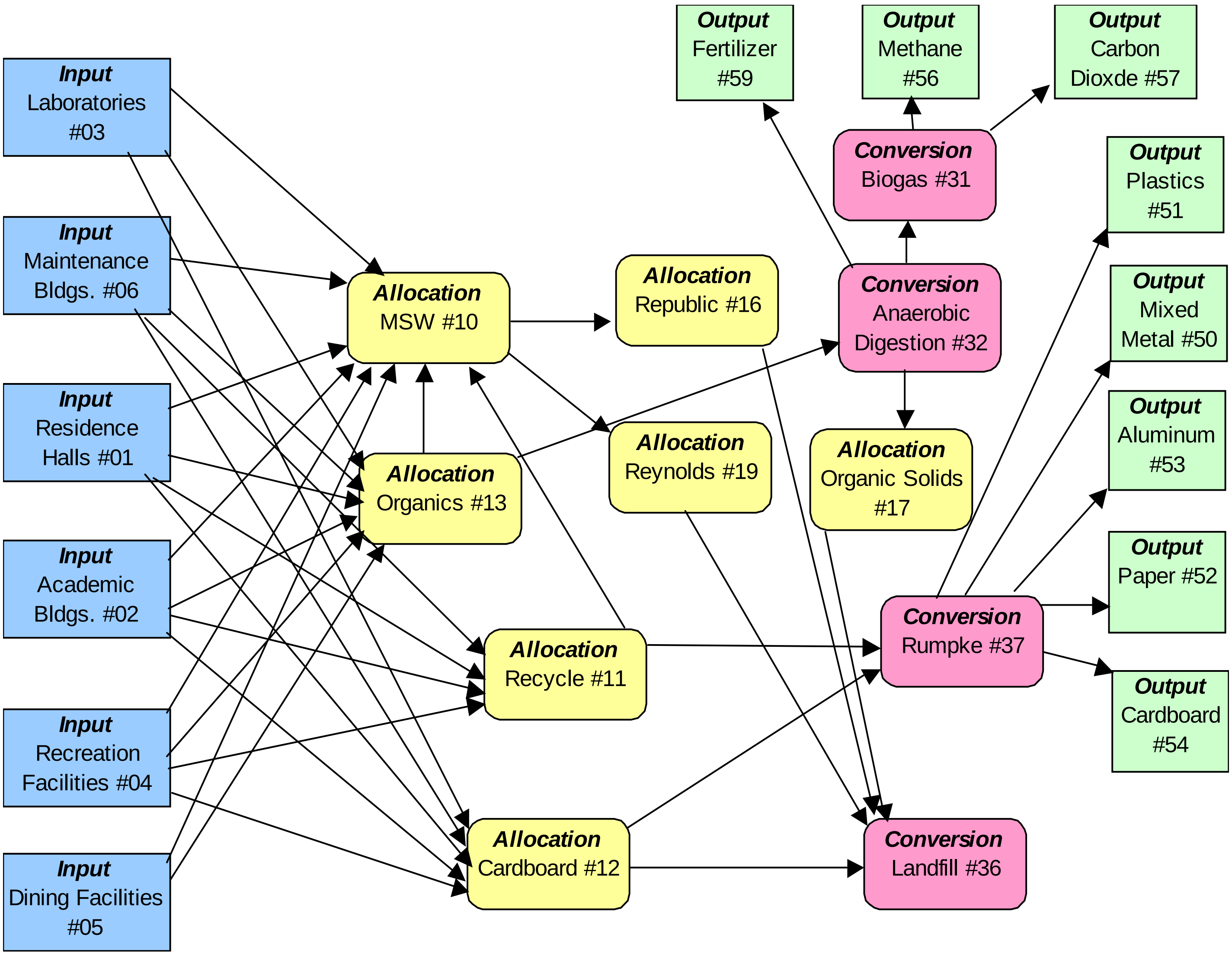
Appendix A: EcoFlow™ Network



Appendix B: Integrated Waste Management & Recycling Survey

Survey: Sustainability and Solid Waste Management at U.S. Colleges and Universities

Introduction:

This survey is part of an undergraduate research project on integrated waste management practices at U.S. colleges and universities being conducted through the Ohio State University School of Environment and Natural Resources. This project involves examining integrated waste management from the perspective of college and university solid waste managers and recycling coordinators to better understand the perceived facilitators and obstacles to the implementation of sustainable waste management practices. The questions below are intended to reveal information on this topic. Surveys are being administered during February and March 2008.

IRB guidelines require that participants be informed of the following:
Participation in the study is completely voluntary and you are welcome to skip questions that you would prefer not to answer for any reason. When findings are presented, you will not be identified without your explicit permission, nor will any information that would make it possible for anyone to identify you. There is no expected risk to you for helping with this study. When all surveys are completed, all responses will be grouped together in any type of report or presentation. In addition, you will be informed of any significant new findings that may influence your willingness to participate in this survey process.

Please include any comments or additional information that you feel is relevant to the questions in this survey, and enter additional comment space wherever necessary. All surveys are being distributed in electronic format, and may be returned via e-mail (barylak.4@osu.edu) or by ground mail (Carson Barylak / 44 East Frambes Ave. Apt. E / Columbus, OH 43201). In some cases, participants will be contacted with follow-up questions to clarify or expand on responses. I greatly appreciate your time and contribution to this project.

Questionnaire:

1. Name: ____

2. At which U.S. college or university are you employed? ____________________________

3. What is your job title? ____

4. For how many years have you held the position listed in question 2?
   a. 1-3 years
   b. 4-6 years
   c. 7-10 years
   d. More than 10 years (Please indicate how many years: ____________)

5. What is the current container recycling rate at your college/university (percentage of total solid waste stream)?
   a. Less than 10 %
   b. 11-20 %
   c. 21-30 %
   d. 31-40 %

e. 41-50 %
f. More than 50 % (Please indicate percentage: ____________)

6. What was the recycling rate at your college/university 5 years ago, if known (percentage of total solid waste stream)?
   a. Less than 10 %
   b. 11-20 %
   c. 21-30 %
   d. 31-40 %
   e. 41-50 %
   f. More than 50 % (Please indicate percentage: ____________)

7. What was the recycling rate at your college/university 10 years ago, if known (percentage of total solid waste stream)?
   a. Less than 10 %
   b. 11-20 %
   c. 21-30 %
   d. 31-40 %
   e. 41-50 %
   f. More than 50 % (Please indicate percentage: ____________)

8. Is your department currently working to increase container recycling rates? If so, please describe current efforts.
   a. No
   b. Yes

   Comments:____
   ____
   ____
   ____

9. Is your institution's recycling program single stream (all recyclable materials mixed and collected together)?
   a. No
   b. Yes

   Comments:____
   ____
   ____
   ____

10. Does your institution receive payment for recyclable products (cardboard, aluminum, etc.)?
    a. No
    b. Yes

    Comments:____
    ____
    ____
    ____

11. If your institution receives payment for recyclable products, which one(s)?
    a. Cardboard
    b. Aluminum
    c. Metals (other than aluminum)

d. Paper
e. Other: ____

12. Do you feel that student activity has influenced waste management practices at your institution?
    a. No
    b. Yes

13. If you feel that student activity has influenced waste management practices at your institution, which of the following have contributed to advances?
    a. Student organization(s) focused on recycling specifically
    b. Student organization(s) focused on general environmental awareness
    c. Student government
    d. Students enrolled in a related course or academic program
    e. Other: ____

    Comments:____
    ____
    ____
    ____

14. Please rank the following (1-5) to indicate which of these options you consider to be the most significant *facilitators* for the implementation of container recycling practices and policies at your institution, with 1 indicating the greatest positive contribution.
    a. _____ Support from administration
    b. _____ Support from faculty and/or staff
    c. _____ Support from students
    d. _____ Financial support (grants, etc.)
    e. _____ Other: ____

    Comments:____
    ____
    ____
    ____

15. Please rank the following (1-5) to indicate which of these options you consider to be the most significant *obstacles* for the implementation of container recycling practices and policies at your institution, with 1 indicating the greatest challenge.
    a. _____ Lack of administrative interest and/or support
    b. _____ Lack of student interest
    c. _____ Infrastructure constraints
    d. _____ Financial constraints
    e. _____ Other: ____

    Comments:____
    ____
    ____
    ____

16. Do you feel that any policies in place at your institution have served to promote sustainable solid waste management practices?
    a. No

b. Yes
Comments:____
____
____
____

17. Do you feel that any policies in place at your institution have hindered the implementation of sustainable solid waste management practices?
    a. No
    b. Yes
    Comments:____
    ____
    ____
    ____

18. To what extent has your department/institution explored composting food wastes?
    a. Not at all
    b. Somewhat, but no action has been taken
    c. Action has been taken but has not yet produced measurable change
    d. Action has been taken and has produced some measurable positive change
    e. Action has been taken and has produced a significant, positive change

    Comments:____
    ____
    ____
    ____

19. To what extent has your department/institution explored energy conservation practices and/or policies?
    a. Not at all
    b. Somewhat, but no action has been taken
    c. Action has been taken but has not yet produced measurable change
    d. Action has been taken and has produced some measurable positive change
    e. Action has been taken and has produced a significant, positive change

    Comments:____
    ____
    ____
    ____

20. To what extent has your department/institution explored sustainable purchasing practices and/or policies?
    a. Not at all
    b. Somewhat, but no action has been taken
    c. Action has been taken but has not yet produced measurable change
    d. Action has been taken and has produced some measurable positive change
    e. Action has been taken and has produced a significant, positive change

    Comments:____
    ____
    ____
    ____

21. To what extent has your department/institution explored academic programs designed to educate students about sustainability?
    a. Not at all
    b. Somewhat, but no action has been taken
    c. Action has been taken but has not yet produced measurable change
    d. Action has been taken and has produced some measurable positive change
    e. Action has been taken and has produced a significant, positive change

    Comments:____
    ____
    ____
    ____

22. Are you willing to answer follow-up questions related to this survey? ______________________

Please include additional comments, references, or appendices in the space below (or attach them). Thank you for participating in this study!