Assessing the Environmental and Monetary Impacts of Waste Management Practices at the University of Massachusetts Amherst

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Work Associated with the University of Massachusetts Amherst

Table of Contents

Executive Summary

The purpose of this research was to create a tool that models the University of Massachusetts Amherst (UMass Amherst) waste system and incorporates environmental factors as well as monetary cost factors into the system. This tool was created in the hopes that it will help decision makers have a more well-rounded view of the system when comparing different waste management options.

The two specific research questions within the waste system we tackled were whether UMass should send its food waste to be composted at Martin's Farm or to the anaerobic digester at Barstow's Farm, and whether UMass should focus on introducing a compost stream into Residential Life or focus on increasing single stream recycling in Residential Life.

After gathering data from both internal and external sources, creating our model, and running our model with multiple cases, we concluded that the anaerobic digester costs $30,000 more annually than composting does but it sequesters 76 more tonnes of carbon equivalent.

	100% MF 0% AD	**50% MF 50% AD**	**0% MF 100% AD**
Cost ($ US 2015)	$107,000	$122,000	$137,000
Emissions ($MTCO_2e$)	-207	-245	-283

Table 1: The cost and emissions of several options to process food waste

We also concluded that it makes more sense for UMass Amherst to focus on increasing single stream recycling in Residential Life rather than implement a compost stream in Residential Life. If we were able to capture the 200 tons of single stream annually that are currently in the trash stream and move that to the recycling stream it would save $13,600 and 476 tonnes of carbon equivalent.

		0% Participation	**50% Participation**	**100% Participation**
Single Stream	Emissions ($MTCO_2e$)	197	-138	-473
	Cost	$130,000	$130,000	$123,000
Compost	Emissions ($MTCO_2e$)	197	184	152
	Cost	$130,000	$154,000	$150,000

Table 2: The cost and emissions of changes in ResLife trash composition depending on participation

There is plenty of opportunity for further research here, such as gathering more thorough information on the rest of the UMass waste system, and also incorporating social costs and benefits into the model.

Background - UMass Waste Management

The University of Massachusetts Amherst (UMass Amherst) waste system has rarely been thoroughly understood by anyone outside of the Office of Waste Management (OWM), despite its active and pervasive role in the functioning of the UMass Amherst campus. The system is surprisingly complex, with an annual budget of $1.3 million dollars and employing 50 OWM personnel to service most buildings on campus daily. The focus of this research is to explore options for improving this system, both environmentally and economically. The main waste streams that the Office of Waste Management handles are (1) the organic waste stream, (2) the single stream recycling waste stream, and (3) the trash waste stream. The sources of these waste streams include: Residential Life, Campus Maintenance, Dining Services & Retail Dining, Campus Center, and Administration and Academics.

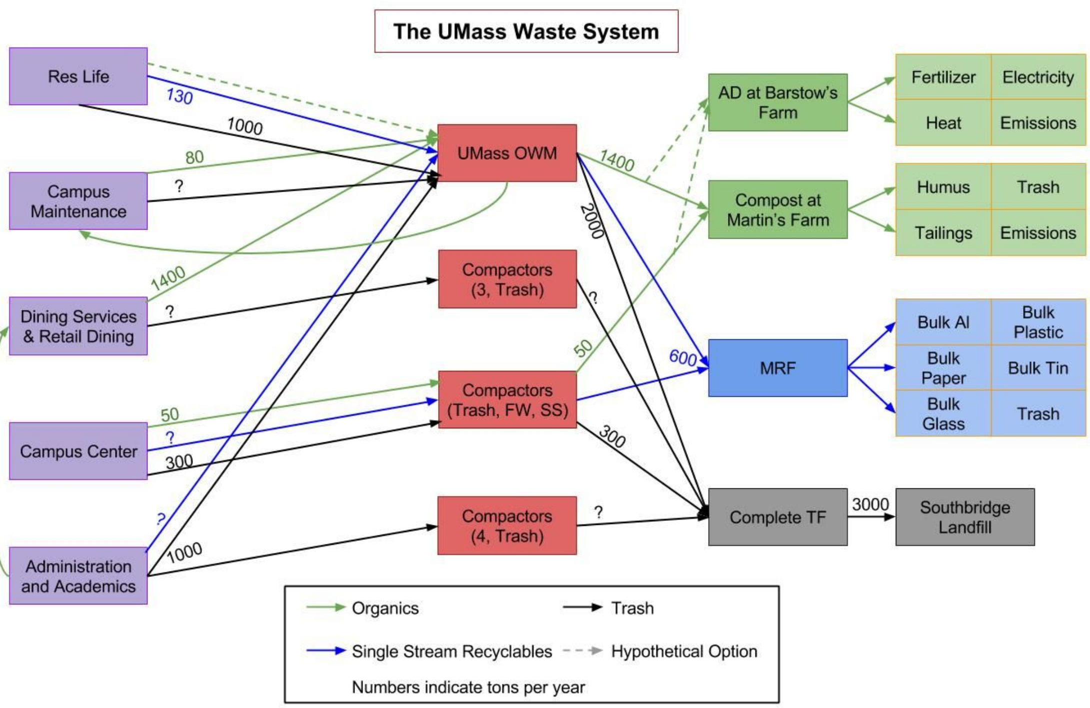

Figure 1. *The UMass Amherst waste stream, depicting the major streams of waste leaving campus.*

Organic Waste (~ 25%? of total campus waste stream)

The organics waste stream is composed of pre and post consumer food waste, compostable papers, compostable plastics, leaves, and yard waste. Dining Services is the main generator of food waste, weighing in with about 1400 tons of food waste per year. This 1400 tons is made up mostly of pre and post consumer food waste, but also includes compostable papers and compostable plastics. Administration and Academics generates a small amount of organics because of retail dining located in these buildings. Food waste is collected, transported to the Office of Waste Management, centralized into a compactor, and picked up to be transported by Dave Wickles Trucking to Martin's Farm, where the organic waste is turned into compost through windrow composting. A compactor is like a dumpster for waste, but it has a mechanism in it that compresses the material in order to reduce its volume. The Campus Center also produces organic waste, but it has its own compactor on site for food waste that is transported directly from the Campus Center to Martin's Farm. Campus Maintenance produces a lot of leaves and yard waste, which is dealt with separately from the rest of organics. The leaves and yard waste is composted in windrows on site at the Office of Waste Management to be used by Campus Maintenance on the grounds of the UMass Amherst campus.

Single Stream (10% of waste stream)

Single Stream Recycling was introduced to UMass Amherst in 2012 as a replacement to dual stream recycling. This practice was adopted in hopes of increasing recycling rates and making recycling on campus an easier, more accessible practice. Single stream recycling at UMass Amherst is the combined recycling of all paper, plastic, glass, and metal recyclables. The main places on campus that generate recyclables are the Campus Center, Administration and Academics, and Residential Life. The Office of Waste Management collects recyclables from Residential Life, academic buildings, and administrative buildings, which are then are centralized into rolloffs at Office of Waste Management. Once centralized, the recyclables are transported to a Single Stream Materials Recycling Facility (MRF) in Springfield, Massachusetts. The Springfield MRF sorts single stream recycling coming from UMass Amherst, as well as various municipalities in Western Massachusetts. When the recyclables arrive at the MRF, automated conveyors separate the recyclables into a dual stream of papers and plastics, glass, and metals. Once separated into papers vs. plastics, glass, and metals it is transported to another MRF in Springfield that sorts and process the recyclables for future use in industry.

Trash (45% of waste stream)

The trash stream at UMass Amherst is composed of all items that are not compostable or recyclable through our current practices on campus. Each area of campus generates trash, and the Office of Waste Management runs trash collections every day. The trash gets centralized in rolloffs on site at the Office of Waste Management and then is transported by Dave Wickles Trucking to Complete Disposal in Holyoke where UMass Amherst's trash is combined with other trash and sent to the Southbridge Landfill. There are a number of compactors on campus: three for the dining halls, one for the campus center, and four for different academic and administrative buildings. These trash compactors are transported directly to Complete Disposal without going to UMass Amherst's Office of Waste Management first.

These three main streams have a lot of contamination in them, meaning compostables get thrown in the trash or trash gets put in the compost, e.g. 20% of the Residential Life trash by weight is organic matter, and an additional 20% by weight is recyclable. In addition to these three waste streams, the OWM deals with bulk items such as furniture which go to the Surplus Barn. The Office of Waste management also deals with miscellaneous items such as tires, mattresses, hazardous items, and electronics; all of these items are dealt with through external contracts to ensure proper disposal.

What's the Problem?

At first glance, the UMass Amherst waste system seems hopelessly complicated and intricate. At second glance, it seems fundamentally simple: everything is generated somewhere on campus, goes through the Office of Waste Management, and then gets trucked away for disposal at other sites. So what is the problem here? The problem is that UMass Amherst does not exist in a bubble. As one of the largest municipalities in Western Mass, UMass waste management decisions have economic and environmental costs and benefits that accrue on campus, in the region, across MA, and to the larger global community. Because of this, and the ever increasing importance UMass, the Massachusetts Department of Environmental Protection (DEP), and the federal government are placing on sustainable practices, it has become increasingly important to make decisions based not only on economic factors, but on environmental ones too. To further this end, the DEP has passed a series of legislation commonly called "waste bans", which restrict the amounts and types of waste that landfills are allowed to accept. In this shifting waste management landscape, OWM needs more holistic decision making tools that will help it allocate resources most effectively and improve our long-term triple bottom line. To help this, we developed a model of the campus waste system that calculates the economic and environmental impacts of different waste management decisions. This model will help eliminate the problem of current waste management decisions on campus being driven solely by the short term economic bottom line.

The purpose of a model is to provide relevant, useful information about the topic in question. In this case, dealing with the UMass Amherst waste stream, the question of relevance rises to prominence. This model reports values which reflect considerations outside the direct sphere of the UMass Amherst campus. Why then are these number relevant to decision makers within the UMass Amherst campus? The reasoning lies in the idea of community impact. UMass Amherst is one of the largest municipalities in western Massachusetts, which means that this waste stream has a large impact on the surrounding communities. By controlling inputs, such as tonnage and destination, the University can dramatically change its impact on the surrounding area.

Research Questions

The Re: Team's research was designed to answer two research questions, which focused on the environmental and monetary risks and benefits of current or hypothetical waste management practices at the University of Massachusetts Amherst.

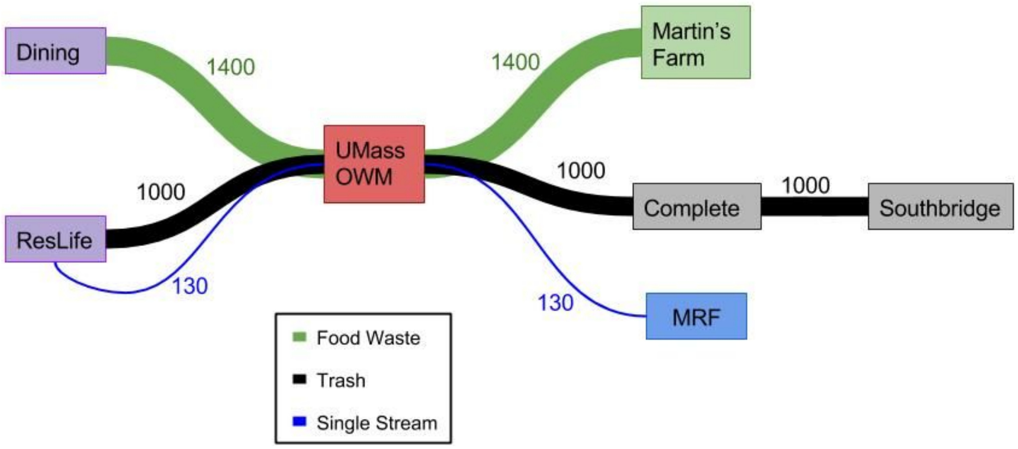

Figure 2. *The piece of the UMass waste system that was closely studied through the research.*

Question 1

To analyze the environmental and monetary risks and benefits of sending our organic waste to Martin's Farm in Greenfield, Massachusetts for windrow composting (our current practice) versus sending organic waste to Barstow's BGreen Anaerobic Digester in Hadley, MA. The anaerobic digestion process captures methane from decomposing organic matter, converts the captured methane to electricity, and then the organics create a fertilizer.

Question 2

To analyze the environmental and monetary risks and benefits of integrating a new compost collection system into Residential Life versus increasing the current single stream recycling rates within Residential Life.

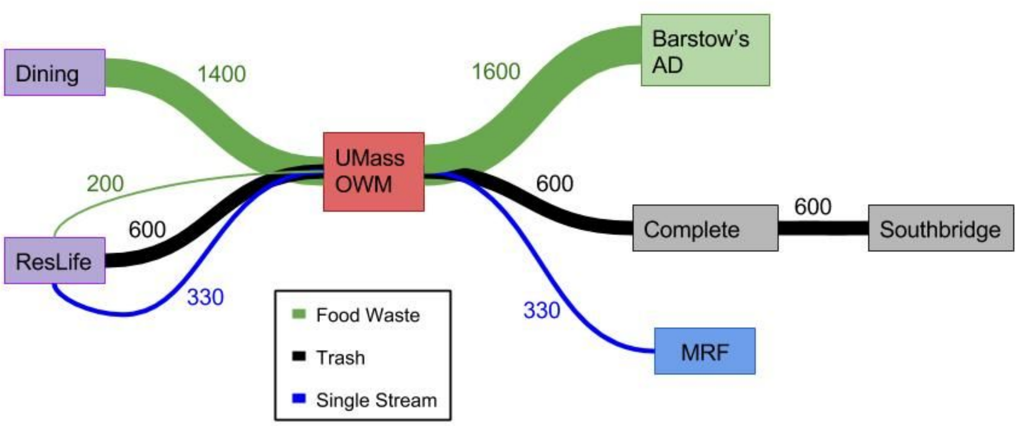

Figure 3. *Possible changes to the UMass waste system that were explored.*

Methods

Model Boundaries

As research widens the lens of decision making, it risks losing focus on the questions that matter to us. How far, then, is too far? This research defined certain boundaries for consideration. The model takes each waste stream as it enters receptacles on campus, and follows it through its trip off campus, all the way to an end processing facility. For example, the model considers organic waste to simply be generated in the dining commons, and follows it from there to Martin's Farm, where it becomes windrow compost. The model does not follow it from there, because it has achieved its environmental impact relevant to our university at that point. Similarly, the model follows single stream recyclables to the recycling facility where it is bundled and shipped to be used. The model does not follow them further, as it uses the Environmental Protection Agency WARM Model's assumptions about recovery effects for recycled materials to interpret the environmental effect of UMass Amherst's recycling. Most of these boundaries were agreed upon by the advisory council overseeing this research. It is because of these boundaries that the model does not reflect exactly the University's actual numbers for carbon emission nor cost. The boundaries extending beyond the campus allows decision makers to glimpse the ripple effect changes made on campus will have in the outside world.

These models while giving a better view of the Waste Management System, do so in broad strokes that do not capture all of the small details. For example, the collection side of the model does not account for the fuel used by idling, changes in time for loading toters, and the embodied energy of trucks and equipment. These inaccuracies with regards to collection are either insignificant or constant despite the proposed changes. The models did not include truck maintenance or cost of salary benefits. Despite these being significant costs to the university and OWM, they would not change if any of the proposals are employed and can unexpectedly change from year to year regardless of changes in waste management.

The model for question two does not consider the costs needed to increase single stream participation. Quantifying these costs would fall outside of the scope of this project and our abilities. Also, most of these costs would fall onto the Residential Life and not the Office of Waste Management. Because of the difficulty of estimating single stream costs and the burden of cost being on Residential Life, these costs were not included in the model. Looking into and modelling campaigns to increase single stream participation would make for a fruitful future research topic. The cost of integrating compost into Residential Life was included in the model because the associated costs are predictable and fall onto the Office of Waste Management.

Despite applying two essential measures, these models do not have considerations of the social risks and benefits of the evaluated options. This is the most neglectful aspect of the models, but the social risks and benefits are impossible to explicitly quantify. Before implementing any change with the guidance of the model, consider how such a change would affect UMass Amherst and the local community.

Data Collection

We collected two types of data: (1) internal (2) external. Internal data came mainly from the Office of Waste Management records or John Pepi, General Manager of the Office of Waste Management. External data came from places where UMass Amherst's waste is sent such as Martin's Farm or Barstow's Farm or studies and publications from sources such as the Environmental Protection Agency.

Internal

Any numbers in the table below that came from "OWM Records" is an average from Office of Waste Management spreadsheets. When possible the average was taken from the calendar years 2013 and 2014. For some numbers, however, there was only information for calendar year 2014 so we calculated the average using monthly data. Since UMass Amherst is a school, the population, and therefore waste, varies depending on the time of year; there are different averages for the school year versus summer/breaks. This was done by looking at a calendar and averaging the numbers from in semester together to come up with the weekly averages and then doing the same for weeks of summer and breaks. When information was not available, estimates were provided by John. John also assisted us in acquiring information from the OWM records.

External

External data was acquired from Barstow's Farm, Martin's Farm, and the Springfield MRF, as well as publications and studies produced by sources such as the Environmental Protection Agency. External data that was needed from Martin's Farm and the Springfield MRF mostly pertained to the amount of diesel fuel that was used throughout the composting and recycling processes. Since UMass Amherst has never used an anaerobic digester, there was limited data and information about the process. Casella Organics, the company that owns Barstow's BGreen Anaerobic Digester, provided information about how their process works, and how organic waste from UMass Amherst could be integrated into their system. For information that wasn't able to be confirmed by the University's resources, such as the amount of diesel fuel Martin's Farm uses to process one ton of compost, we used information from sources such as the Department of Energy and Climate Change, the EPA's WARM model, the National Renewable Energy Laboratory.

Model Construction

To model questions one and two, the open source modelling platform Insight Maker was used for initial conceptual design and prototyping. To increase flexibility, presentability, and usability for our client, the final model was delivered in a spreadsheet format. The final model's calculations are based on several inputs entered by the user which pertain to the cost and emissions of collection, transportation, and processing of the current or proposed system. For collection and transportation, one would enter the frequency, route length, and labor costs associated with each. For processing, the model depends on the tonnage, tipping fee, as well as emissions and fuel use per ton.

Once these inputs are entered, the model returns the total annual costs and emissions as well as a breakdown by transportation, collection, and transportation. This allows decision makers to easily conduct scenario analyses and quickly see the economic and environmental impacts of different OWM decisions. Cost has been practically the only factor in decision making for the OWM, but it is important to incorporate a more holistic view in order to take into account how UMass Amherst's waste affects the environment as well. The two metrics in this model are cost and CO_2 equivalent. This allows the user to consider both the environmental and monetary risks and benefits of different waste management options.

Technical Review

Modeling validity requires a significant level of rigorousness for the cross checking of source parameters. This model went through several iterations under the approval of the advisory board, who pointed out oversights and double-counting of certain model values against different outcomes. For example, in one iteration, the model used an estimated thirty gallons per ton of compost on Martin's Farm, making windrow composting seem utterly ineffective in combating greenhouse emissions. However, after rechecking and comparing with the representatives from Martin's Farm, we found that the total gallons used is more appropriately six per ton. This significantly changed the model's computations, and thus represent an increase in validity due to the revision of an estimated parameter to a verifiable value.

Results

Question 1

	100% MF 0% AD	**50% MF 50% AD**	**0% MF 100% AD**
Cost ($ US 2015)	$107,000	$122,000	$137,000
Emissions (MTCO_2e)	-207	-245	-283

Table 1: *The cost and emissions of several options to process food waste*

Table 1 gives the associated risks and benefits for how organics are processed after they leave UMass Amherst. The three options are sending all of organics to be composted at Martins Farms (100% MF 0% AD), sending half to be composted at Martins Farms and half sent to the anaerobic digester at Barstow Farms (50% MF 50% AD), and sending all of the organics to the anaerobic digester at Barstow Farms (0% MF 100% AD). When considering the best options to manage the organics coming from the dining halls and retail dining, the best option would be to start sending our organics to the anaerobic digester. Despite the increased cost of sending organics to Barstow Farms, anaerobic digestion has the added benefit of sequestering more carbon, generating energy, as well as producing fertilizer.

Question 2

		0% Participation	**50% Participation**	**100% Participation**
Single Stream	Emissions ($MTCO_2e$)	197	-138	-473
	Cost	$130,000	$130,000	$123,000
Compost	Emissions ($MTCO_2e$)	197	184	152
	Cost	$130,000	$154,000	$150,000

Table 2: *The cost and emissions of changes in ResLife trash composition depending on participation*

Table 2 depicts how participation in one of two possible programs to improve the composition of trash in Residential Life would affect the emissions from trash in the dorms. Single Stream recycling avoids CO_2e at a much higher rate than composting food waste would. Single Stream has the additional advantage of having an established collection system where composting in residential life does not. Because of Single Stream's established collection system and high amount of avoided carbon per ton it makes more sense to reduce the amount of recyclables in the trash before implementing a composting program.

<u>Results and Recommendations</u>

Sources of Uncertainty

This model uses both site specific and general sources, and there are a number of data values which are estimates. The general values, while well documented, may not be accurate to the specifics of UMass Amherst's situation. The specific numbers, though obtained from members of industry, have not been rigorously back-checked. The estimates are just that, estimates. Because of these factors, there is some vagueness and uncertainty about the values the model gives.

The records from the Office of Waste Management may have some error in them, or may be missing some information. In certain cases, data was only available for one previous year which could be made more accurate with access to data over a longer time period.

Best Options

According to the models, the best option to employ would be first to improve participation in single stream recycling in the dorms. Due to the high impact of recycling from diverting waste from landfills and conserving natural resources, increasing single stream participation will have the most beneficial environmental impact. The next best option would be to start sending organics to the anaerobic digester on Barstow's Farm instead of composting them at Martin's Farm. This would cost an additional $30,000 to the university, but this would not be an excessive cost when compared to the current $150,000. Sending organics to an AD would divert more CO_2e than composting as well as generating electricity.

Feasibility

While considering solely the economic concerns for any decision is shortsighted, considering solely the environmental impacts is equally so. Therefore, a practicality comparison must be made between different options based on both environmental and economic constraints. Consider firstly the choice between Martin's Farm windrow composting and Barstow's Farm Anaerobic Digester. The investment of $30,000 into the anaerobic digester results in a decrease of 76 tonnes of CO_2e. By contrast, the investment of $11,000 into increasing single stream recycling in the residential halls results in the saving of 350 tonnes of CO_2e. Finally the investment of $55,000 up front, plus $6,000 annually into providing compost in the residential buildings would result in a savings of about 60 tonnes of CO_2e annually.

Recommendations

The models created here, while quite complex, should be expounded on by future researchers. Both models consider cost, emissions, and energy, but these metrics do not encompass all factors that impact the waste management system and practices at UMass Amherst. In future research, the Re:Team recommend that there be many additions in the model, so that it may more accurately represent the environmental and monetary risk and benefits of the analyzed waste management practices. Our recommended additions to the model include embodied cost and embodied energy of vehicles used in collection, transportation, and processing of waste. It would also be useful to include costs of benefits of state employed laborers into the cost of labor. In order to create a more complex study, it is recommended that future researchers integrate the two models and create additional cases for disposal in this model. Finally, it is suggested the social costs and benefits of the waste management practices be considered in future research, because each practice carried out by UMass Amherst impacts local people and the economy.

Conclusion

The objective of our study was to create models of the UMass Amherst waste system and then use these models to answer two questions regarding proposed changes to the UMass Amherst waste system. By running the models through several scenarios, we found that the best options for UMass Amherst to implement are to start sending food waste to an anaerobic digester and to increase single stream recycling in Residential Life. Both of these options would reduce emissions and do not require large monetary investments. It is our hope that our results and models will be considered and utilized in future decision making for waste management practices at UMass Amherst.

Appendix A: Model Assumptions

With these research questions come assumptions that must be made in order to clarify why some details are either included in or omitted from our model. The first research question regarding composting and anaerobic digestion of organic waste, required the basic assumption that the number of trucks used for transportation of organic waste will remain the same regardless of whether it is sent to Martin's Farm or Barstow's Farm. It was assumed that regardless of the amount of organic waste that is sent to compost, UMass Amherst is under contract to pay a fixed fee per ton of waste. Currently, Barstow's Farm does not accept organic waste unless it has been made into slurry, so UMass Amherst' organic waste is not currently compatible with the anaerobic digester. However, Barstow's Farm will be installing a grinder and slurry facility on site during the summer of 2015. From this information, it has been assumed UMass Amherst will be using Wickles trucks to deliver organic waste to Barstow's Farm, where it would be further processed. Additionally, it was assumed that if UMass Amherst uses Wickles trucking to transport organic waste to the anaerobic digester, current practices for collection of organic waste will be used.

The second research question was a bit more complex, and therefore required more assumptions in order to address and analyze the questions in the model. The first assumption was that all vehicles in the model are using number two diesel oil as fuel. It has also been assumed that the cost of transportation for compost would be the same if composting was integrated into Residential Life, because Residential Life will not yield enough compost to warrant additional transportation and incur additional cost. Additionally, it was assumed that the workers driving the compost and single stream collection trucks receive the same hourly wage for their labor.

For the option of increasing single stream recycling in Residential Life, the main assumption is that recyclables are sent to the Materials Recycling Facility in Springfield and trash is sent to the Southbridge Landfill. If this option is chosen, it is assumed that there will be no difference in the cost of collection, because it is expected that the increase in recyclables will not be significant enough to change the number of collection trips needed. From this, the model assumes that the transportations costs for recyclables to the Materials Recycling Facility in Springfield would remain the same. Similarly, regardless of the amount of single stream recyclables UMass Amherst is able to divert from the trash stream, the transportation cost to bring waste to the Southbridge Landfill will remain the same. If either option proposed in question two is adopted, it has been assumed that Residential Life will take on the costs necessary for new signs, education, and outreach.

Appendix B: Model Parameters

Data Name	Units	Number	Source
Tons Organics	tons/week	38.6 school year 8.8 summer/breaks	OWM Records "2014-MaterialAnalysisReport", "ScaleALLIN7-1-11 TODATE"
Length of Compost Collection Route	miles	4	Google Maps, John Pepi
mpg of Compost Collection Truck	miles/gallon	8.97	Fleet Services, Alicia Santini
Fuel Cost	Dollars/gallon	$3.01	Fleet Services, Alicia Santini
Frequency of Compost Collection	Routes/week	9.9 school year 3.1 summer/breaks	OWM records "2014-MaterialAnalysisReport", "ScaleALLIN7-1-11 TODATE"
Collection Wage	Dollars/hour	$20	OWM records, John Pepi "FY14FullYearAllocationWasteManagement1-26-15"
Labor per Compost Collection	Man hours	6	John Pepi
CO2e per gallon of fuel	kg CO2e/gallon diesel	11.96	https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/69554/pb13773-ghg-conversion-factors-2012.pdf
BTU per gallon of fuel	BTU/gallon diesel	128,488	Chemical Analysis of Diesel Fuel
Frequency of Compost Transports	Transports/week	3.8 school year 1.14 summer/breaks	OWM Records "CY14OUT_Sorted"

Cost to Wickles to transport to Martins	Dollars/Transport	$102.09	OWM Records "WickleInvoiceCheck1-2015"
mpg Wickles Truck	miles/gallon	4.2	Dave Wickles
Distance to Martins	miles (round trip)	41.2	Google Maps
Gallons fuel burned on Martin's Farm	Gallons diesel/ton food waste	6	guesses for fuel usage on MF and time to process compost
Compost Emissions/ton	Kilograms CO2e/Ton food waste	-240	Environmental Protection Agency
Cost to Martins/ton	Dollars/Ton FW	$35.40	OWM, John Pepi
Wickles Cost to transport to Barstow	Dollars/Transport	$80	OWM Records "WickleInvoiceCheck1-2015" and Wickles Bid (print out)
Distance to Barstow	miles (round trip)	20.2	Google Maps
Barstow Equipment use	BTU/ton FW	39,700	Call Barstow's Farm/ check fuel usage, chemical analysis
BTU generated per ton of AD organics	BTU/ton FW	283,000	estimated based on total production of fertilizer from AD, assuming generator is running 24/7 at 285kW
AD flaring	kg CO2e/ton FW	0	Call Barstow's Farm/ Check EMCON files
CO2e/ton offset from alternative fuel	kg CO2e/ton FW	22.03	Reached through ISO NE fuel mix data and calculations from average CO2e/ton of disparate fuels
AD cost/ton	Dollars/ton	$60	http://www.nrel.gov/docs/fy13osti/57082.

			pdf
Weekly RL trash tonnage without diversion	Tons/week	33.33	OWM, John Pepi
Amount of organics in trash	Tons/week	6.67	OWM, John Pepi
Amount of recyclables in trash	Tons/week	6.67	OWM, John Pepi
$/new truck	Dollars	$80,000	OWM, John Pepi "RLFoodWasteCollectionCosts"
# new trucks	Trucks	1	Fleet services
$/compost toter	Dollars	$163	OWM, John Pepi
$/recycling toter	Dollars	$163	OWM, John Pepi
# new recycle toters	Toters	200	OWM, John Pepi
# new compost toters	Toters	60	OWM, John Pepi
$/compostable bag	Dollars	$0.97	OWM, John Pepi
# new bags	# bags	2500	
Length of RL Collection	Miles	12	OWM, Steve
Frequency of RL Compost Collection	Collections/week	4	OWM, John Pepi, EH&S
Hours of Labor per RL compost Collection	man hours	4 +2 hrs/wk for washing toters	OWM, John Pepi "RLFoodWasteCollectionCosts"
mpg of trash collection truck	Miles/Gallon	3.02	Fleet Services, Alicia Santini
Frequency of trash collection	Collections/week	7	OWM, John Pepi
Trash Tipping Fee per Ton	$/ton	67	OWM, John Pepi

SS Tipping Fee per ton	$/ton	0	OWM, John Pepi
LF emissions/ton	kg CO_2e/ton trash	135.6	Environmental Protection Agency Warm Model
Southbridge gal per ton to process trash	gallons diesel/ton trash	0.15	estimate from Southbridge LF
Distance to Southbridge	miles (round trip)	88	Google Maps
Frequency of Trash Transport	transports/wk	3.97 school year	OWM Records, "CY14OUT_Sorted"
Trash Transport Cost	$/transport	$160	OWM Records, "WICKLEINVOICE CHECK1-2015"
RL Trash Collection Time	man hours	8	OWM, Steve
CO_2e displaced per SS ton	kg CO_2e/ton	3,000	Environmental Protection Agency
BTU displaced per ton of SS	BTU/ton	15,000,000	Environmental Protection Agency

Appendix C: Cost Calculation Process

Calculation Name	**Equation**
Model 1	
Collection Cost	[Collection Gallons of Fuel]*[Cost per gallon of fuel]+[Frequency of collection]*[Labor per Collection]*[Collection Wage]
Transportation Cost	[Trips per week]*(([% to Martin]/100)*[Wickles Cost to transport to Martins]+(1-[% to Martin]/100)*[Wickles Cost to transport to Bartsow])
Weekly Cost	[Collection cost]+[Transportation Cost]+[Martin Farm]*[$Martin/ton]+[AD Barstow]*[$AD/ton]
Model 2	
Compost Collection Cost	[Compost Collection Fuel Usage]*[Cost per gallon of fuel]+[Hours of Labor per Collection]*[Frequency of Compost Collection]*[Hourly Wage]
Single Stream Collection Cost	[Fuel usage of SS collection]*[Cost per gallon of fuel]+[Frequency of SS Collection]*[Hours Labor per SS Collection]*[Hourly Wage]
Trash Collection Cost	[Frequency of trash collection]*[Length of trash collection]/[mpg of collection truck]*[Cost per gallon of fuel]+[Frequency of trash collection]*[Hours labor per collection]*[Hourly Wage]
Tipping Fees	[SS Tipping Fee per ton]*[Tons SS]+[Trash Tipping Fee per Ton]*[Weekly Trash Tonnage]+[Compost tipping fee per ton]*[Tons Compost]
Single Stream Transport Cost	[Frequency of SS transportation]*[Wickles Cost to Transport SS]
Trash Transport Cost	[Wickles Cost to Transport]*[Frequency of trash transportation to southbridge]
Total Compostable Bag Cost	[$/compostable bag]*[# new compostable bags]
Total Cost of Single Stream Infrastructure	[Total toter cost]
Total cost of Compost	[Total truck cost]+[Total toter cost]+[Total bag cost]

Infrastructure	
Total Compost Toter Cost	[$/toter]*[# new toters]
Total Single Stream Toter Cost	[$/toter]*[# new toters]

Appendix D: Carbon Footprint Calculation Process

Calculation Name	**Equation**
Model 1	
CO2e From the Anaerobic Digester Weekly	[AD Flaring]+([CO2e/ton offest from Alternative fuel]-[AD diversion of CO2e])*[AD Barstow]
CO2e from Martin's Farm Weekly	([CO2e per gallon of diesel]*[Gallons/ton Fuel burned on MF]+[Martin Farms Compost Emissions per ton])*[Martin Farm]
CO2e of Collection and Transportation	[Weekly Transportation and Collection fuel]*[CO2e per gallon of diesel]
Model 2	
Weekly Compost CO2e	[Compost CO2e/ton]*[Tons Compost]+[Gals used on MF/ton]*[CO2e/gal]*[Tons Compost]+[Fuel Usage of Compost Collection and Transportation]*[CO2e/gal]
Weekly Single Stream CO2e	([Total SS fuel usage])*[CO2e/gal]-[CO2e displaced per SS ton]*[Tons SS]
Weekly Trash CO2e	[Weekly Trash Tonnage]*[LF emission/ton]+[Weekly Trash Tonnage]*[Southbridge gal per ton to process trash]*[CO2e/gal]+[Fuel usage of trash collection and transportation]*[CO2e/gal]