2016

Monitoring Waste to Minimize Waste at the University of Massachusetts Amherst

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Masi, Dylan J.; Shea, Timothy C.; Downs, Jacob M.; and Chou, Amy W., "Monitoring Waste to Minimize Waste at the University of Massachusetts Amherst" (2016). *Student Showcase*. 15.
Retrieved from https://scholarworks.umass.edu/sustainableumass_studentshowcase/15

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NatSci289H – Integrated Scientific Communication

1. Executive Summary

The University of Massachusetts Amherst is committed to sustainability, however, the campus could further reduce its costs and save energy by optimizing the current method of waste removal. The Intergovernmental Panel on Climate Change predicts that by the end of the century, Earth's average temperature will rise by 11 degrees Fahrenheit unless society takes action to reduce greenhouse gas emissions. According to the EPA, about one-third of carbon emissions in the U.S. come from transportation. Campus garbage bins are collected by carbon-emitting trucks daily, and large truckable waste compactors are collected about three times per week. The amount of harmful carbon emissions released by trucking all of the compactors to their disposal sites totals 9,600 pounds of CO_2 (the weight of 12 grand pianos) every week. In this analysis, the current waste removal system is investigated and a method is proposed to save UMass money and energy by reducing the number of waste collections. Initial research focused on how traditional bins could be replaced with solar-powered compactors from Bigbelly Solar Inc. to reduce pickup frequency and generate revenue from separating waste. Findings indicate that solar compactors alone would not have a worthwhile impact on the energy consumption of the UMass campus. Alternatively, a monitoring system that reduces how frequently waste compactors are hauled from campus would have greater impact, saving $1,000 every two weeks, reducing harmful carbon emissions, and using less diesel fuel. Due to the current environmental crisis, UMass should take action to reduce its carbon footprint through this economically favorable system.

2. Introduction

The University of Massachusetts Amherst prides itself on obtaining the "gold" rating for campus sustainability (Figure 1) from the Association for the Advancement of Sustainability of Higher Education [1]; however, a gold rating is no excuse to waste energy. The amount of energy and resources involved in handling the municipal solid waste at UMass, home to 22,000 undergraduates [2], leads to detrimental effects on the environment. These effects include litter from overflowing waste bins and carbon emissions released by waste collection vehicles [3]. Currently, waste is collected on a set schedule, meaning that it is often collected before necessary [4]. This leads to excessive energy usage and trips by carbon-emitting trucks [4]. UMass aims to improve its Sustainability, Innovation and Engagement Fund (SIEF) score [5]. To minimize overflowing bins, reduce litter pickup and improve the campus' SIEF score, UMass could support a more efficient waste management solution. Switching campus waste collections from scheduled to as-needed would reduce excessive trips. Bigbelly Solar Inc. has a model which utilizes solar energy to compact trash [6]. This model promotes renewable energy, reduces waste collections, and minimizes landfill disposal by encouraging waste separation [6]. Another solution involves monitoring the capacity of the large truckable waste compactors on campus to lower collection frequency, reducing carbon emissions and saving energy [7]. This project analyzes both solutions and how they would affect the UMass campus. In order to mitigate UMass' environmental impact, the campus needs a solution that is cost-effective, widely-applicable, and simple to implement.

Figure 1. UMass Amherst achieves Gold STARS sustainability rating in 2014.

3. Best Commercially Available Technology - How Does It Work?

*The following analysis was written before crucial economic information that invalidated the Bigbelly solar compactors idea; the updated proposal can be found on pages 10-12

Traditional waste bins on campus fill up quickly, especially with 22,000 undergraduates at UMass Amherst. [8] The energy and resources needed to handle this waste leads to negative environmental impacts such as requiring frequent waste collections by carbon-emitting vehicles and overflowing resulting in litter. Bigbelly solar powered waste compactors mitigate these issues by gathering data on the fullness of the waste receptacle and compacting the waste to create more storage, while their enclosed design prevents garbage from blowing out [9]. The compactions are performed using power that is harnessed by a solar panel located atop the compactor [9]. The option for separate compost, recycling, and trash units may facilitate the participation in sorting waste [8]. Bigbelly's innovative use of solar power, compaction technology and live-feed data allows for efficient waste management and removal.

Bigbelly's solar compactors use photovoltaic (PV) solar cells to convert the sun's energy into electricity [9]. A Bigbelly compactor is powered by its own solar panel, a carbon-free source of energy, eliminating the need for a connection to the electric grid [9]. The PV cell takes advantage of peak sunlight conditions to store energy in an internal battery for future compactions [9]. A PV cell is made up of semiconductors (materials which have the ability to generate electricity) [10]. When energy from sunlight reaches the PV cell, it breaks electrons free from the atoms contained within the semiconductors [10,11]. Positive and negative charges within the semiconductor are drawn away from each other into a circuit [10]. At the other end of the circuit (the battery), the positive and negative charges join back up, and electrical energy is stored in the battery [9,10]. In order to support the compactor's average of 15 compactions/day, a control system facilitates the transfer of electricity from the battery to the compaction mechanism when necessary [9].

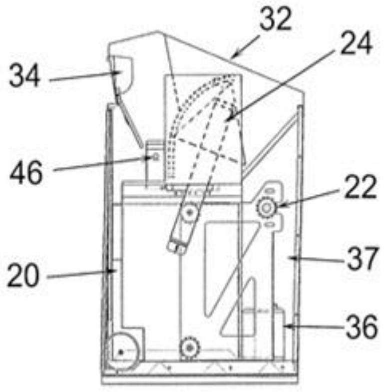

Figure 2. The compaction ram in the solar compactor allows for more storage of waste, therefore fewer collections.

To power the compaction processes, the solar compactors access the stored energy from the battery. Electricity leaves the solar panel in the form of direct current (DC) voltage and then goes through an inverter that converts the DC voltage to alternating current (AC) voltage - the type of electricity required to power the compaction mechanism [9]. The compacting mechanism is either a chain-driven compacting ram (Figure 2, part #24), or a hydraulic arm that is powered by a hydraulic fluid pump [9]. The compacting ram has a plunge of eight inches, meaning that it can press the contents of the bin eight inches lower than the starting height, and it has a compacting force of 2,000 pounds [9]. The unit has an overall compaction ratio of 4:1 (it can condense trash into ¼ its original volume) [9]. Utilizing stored energy and conserving space is what differentiates Bigbelly waste stations from traditional trash cans.

Bigbelly produces two systems, the Smartbelly station and the Bigbelly Station [12]. Smartbelly can keep different types of recyclable materials separated (this is known as multi-stream recycling) [12]. On the other hand, a single Bigbelly compactor has a capacity of 150 gallons; three times more than the Smartbelly station and five times more than regular trash bins [12]. These compactors communicate with Bigbelly through a live-feed of data to offer active monitoring of the compactor's fullness [9]. The live-feed provides an intelligent and dynamic way to notify the trash collection company when the bin must be emptied [12]. Solar compactors continuously keep trash compacted, allowing for more storage and fewer collections by carbon-emitting vehicles [9]. The Bigbelly station and the Smartbelly station can be paired to create customized waste stations that could include a mixed recycling compactor, a trash compactor, and a compost compactor [12]. All three compactors have an enclosed design that prevents bad odors from escaping and keeps out animals and snow [9]. The ability to customize a Bigbelly station would allow the campus to customize trash receptacles at different locations throughout campus. For instance, bins near the dining halls would incorporate composting, whereas those bins near classroom buildings would contain large trash receptacles.

The Smartbelly and Bigbelly solar compactors make use of modern solar, composting and monitoring technology to condense and efficiently remove their contents. UMass should strongly consider switching from its outdated waste bins to solar compactors to revolutionize energy savings in terms of waste handling.

4. Best Commercially Available Technology – Advantages and Disadvantages

*The following analysis was written before crucial economic information that invalidated the Bigbelly solar compactors idea; the updated proposal can be found on pages 10-12

In order for UMass Amherst to consider implementing solar-powered waste compactors, the compactors' environmental benefits must be weighed against their costs. Bigbelly solar compactors reduce litter from overflowing waste bins, reduce carbon emissions released by garbage vehicles, and sort waste to keep it out of landfills [9,14]. These specialized compactors have a relatively high cost compared to the funding available from the SIEF [5,14], yet their return on investment could make them more affordable [15]. Investing in solar-powered waste compactors would demonstrate that UMass is commitment to sustainability, and could inspire further change.

In terms of energy production and usage, Bigbelly solar compactors benefit campus more than traditional waste receptacles. Solar compactors operate independently from the electric grid because their solar panels generate carbon-free energy [9]. The battery mechanism in a Bigbelly stores up to 600 Watt-hours of electricity; more than enough to power the unit's energy demands [9]. The compactors can operate for two weeks on reserve energy, assuming they run the average number of compactions (15 per day) [6]. Based on the energy in diesel fuel, one garbage truck compaction cycle uses about 34.14 megajoules [17], enough to power a 2011 iMac/Intel desktop computer for 56 weeks [16]. Bigbelly saves this energy by pre-compacting trash. In addition, the energy saved by reducing one campus-wide waste collection trip is enough to power the average American household for over two days (based on a 25% conversion efficiency of diesel fuel to energy) [18,19]. As shown, there are only advantages to Bigbelly compactors regarding energy; big energy savings as well as the utilization of a clean energy source.

Bigbelly solar compactors include features that make them more environmentally attractive than traditional waste receptacles [9]. Many waste disposal sites on campus do not include a composting option, and recycling bins are labeled "bottles and cans" despite being single-stream. Bigbelly can group individual compactors for trash, mixed recycling, and compost [9]. Compost and recycling placed in the bins would not end up in landfills. The enclosed design of these units reduces litter. [9]. Bigbelly bins can hold four times more waste than traditional bins, meaning fewer collections and trips to processing and landfill destinations by carbon-emitting vehicles [9]. Eliminating one of campus' waste collection trips would prevent the emission of 161 pounds of CO_2 due to diesel combustion [20,21]. On the downside, batteries and solar panels wear out over time and UMass will be responsible for recycling them [6]. The lead-acid battery gets recycled at a battery retailer to prevent leakage of harmful chemicals into the environment [22]. Solar panels have a lifespan of about twenty-five years, and environmental harm is less of an issue [23]. Introducing these environmental benefits to campus would make it a cleaner, more environmentally-conscious place.

The UMass Amherst Sustainability Innovation and Engagement Fund (SIEF) provides up to $12,500 [5]; therefore, it is important for compactors to generate revenue. Bigbelly's solar compactors are economically problematic due to high startup costs [6]. A compactor costs $3095/unit, $1000 for its lifetime software subscription, and $102.5 for a yearly warranty (which covers battery replacement) [6]. In contrast, UMass profits $30.90 per ton of compostable materials and $72.46 per ton of recyclable materials (paper products, plastic/metal cans) [15]. Recycling and compost account for a total of 68.1% of an individual's waste (Figure 3), or 0.544 tons of recyclable waste per person per year [24]. To be profitable on campus over five years, 580 people would have to sort one pound of their waste into a Bigbelly station every day. This high number of necessary participants would make it hard to meet the SIEF requirement of a five-year return on investment [23]. However, Bigbelly compactors become more cost-effective over time.

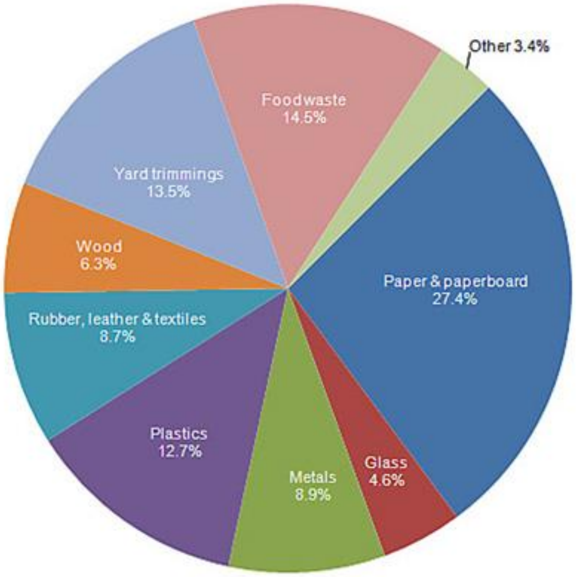

Figure 3. According to the EPA, recycling and compost account for about 68% of an individual's waste.

From manufacturing to everyday use, Bigbelly solar compactors are socially equitable. Solar compactors can be placed anywhere a waste bin would have been, requiring no alteration to the landscape where they are installed and yielding no additional labor for maintenance workers. Solar compactors provide an opportunity to engage the campus community in sustainable initiatives because anyone is free to use them. Users will not directly benefit from compactors, unless the University decides to invest any financial savings into something that would benefit the entire campus.

With 22,000 undergraduates [2] each producing over four pounds of waste per day [25], UMass needs to switch to a method of waste handling which will require fewer trips by environmentally polluting vehicles and encourage separation of waste before it reaches landfills. Although there are some downsides including steep startup costs, Bigbelly solar compactors mainly excel in the sustainability categories of: energy, environment, and equity.

5. Promising Future Technology – Explainer

*The following analysis was written before crucial economic information that invalidated the Bigbelly solar compactors idea; the updated proposal can be found on pages 10 – 12

Replacing traditional waste receptacles at UMass Amherst with solar waste compactors mitigates environmental harm caused by handling the large amount of waste produced on campus [9]. One might ask, what is stopping the switch to solar compactors? These units are expensive ($4095/unit); furthermore, their return on investment mainly depends on the number of participants who use the compactor and separate their waste. Adding a device which could quantify the “environmental savings” based on the amount of recycling or compost added to the bins might encourage more participation, and therefore a quicker return on investment for the solar compactors.

The counter used in water bottle refill stations at UMass could be applied to solar compactors to increase participation in separating waste. The bottle filling stations are equipped with Green Ticker™, a visual display showing the number of 12 oz. plastic bottles that each station has eliminated from disposal in landfills [26]. Although there is no research on whether or not this immediate feedback encouraged participation, a study on the effects of positive reinforcement in a school setting found that behavior was greatly influenced for the better; in one instance the amount of litter in the lunchroom decreased by 94% [36]. Bigbelly solar compactors could use a counter to calculate the number of trees conserved, or square feet of fertilizer generated from compost. This calculation will be based on the weight of the material in the bin (assuming all of the recycling material is paper-based), and on how many pounds of paper a tree provides. Bigbelly compactors already contain a sensor that calculates the volume of material by measuring pressure against the compaction ram [9]. Multiplying the volume by the average specific volume of recycling materials would provide the total weight of the material. Over time, more recycling and compost would accumulate and the counter’s results would improve. In order to gain quicker return on investment by collecting recycling and compost, the addition of a positive-feedback device might motivate more people to use the compactors and sort their waste, resulting in environmental savings.

A solar compactor should use its abundance of power [9] to its advantage. Diverting excess power to an electronic “environmental savings” counter (Figure 4) in order to promote use of the compactor would be an efficient use of energy. Participants would be encouraged to recycle more often due to the fact that they could quantify their direct impact by recycling. Luckily, such a counter would only use 0.018 watt-hours per day [9,27,28], a nearly arbitrary energy cost considering that a single compaction uses 3 watt-hours from a 600 watt-hour battery [9]. With so much excess energy stored in the battery, it makes sense to further increase the functions of the solar compactor.

People may be more inclined to recycle and compost if they knew how much material they use. The average American uses approximately 680 pounds of paper each year [29]. Unfortunately, only 63.5% of this amount was recycled in 2013 [30]. An average-sized tree produces about 200 pounds of paper, or 2000 sheets [31]. For every 20 pounds of recycled paper, the counter will tell users that one tenth of a tree has been saved (assuming that 100% of recycled paper is reused). Additionally, composted material can be used as fertilizer. A gardening rule is to use 0.05 pounds of fertilizer per square foot [32]. One pound of organic waste fertilizes 20 square feet of garden space. A device that allows people to see the environmental savings of recycling and composting can be used as an educational tool that aims to increase these efforts.

Figure 4. Displaying positive feedback on the solar compactors may increase participation while allowing users to see their environmental impact.

Solar compactors hold more waste than traditional garbage receptacles, require less trips by carbon-emitting vehicles to and from landfills, and their enclosed design reduces litter. Adding an electronic counter to the compactor would be an innovative way to increase awareness of the importance of recycling and composting. The counter would inform users how much of an impact their efforts make, whether the impact is saving trees or creating fertilizer. When awareness is raised, more people may use the solar compactor, speeding up the unit’s return on investment. The financial gain from a greater return on investment would allow UMass to purchase additional compactors in order to magnify their environmental benefits.

6. Promising Future Technology – Advantages and Disadvantages

The economic feasibility of implementing an environmental solution determines whether or not the campus will consider it. Instead of the previous focus on introducing small, costly solar compactors on campus (which have a low return on investment [R.O.I.] for campus according to recent discoveries), the team now proposes mounting a monitoring system on campus' existing waste compactors that will alert waste haulers when the compactor is nearly full, reducing the amount of trips to disposal facilities [7].

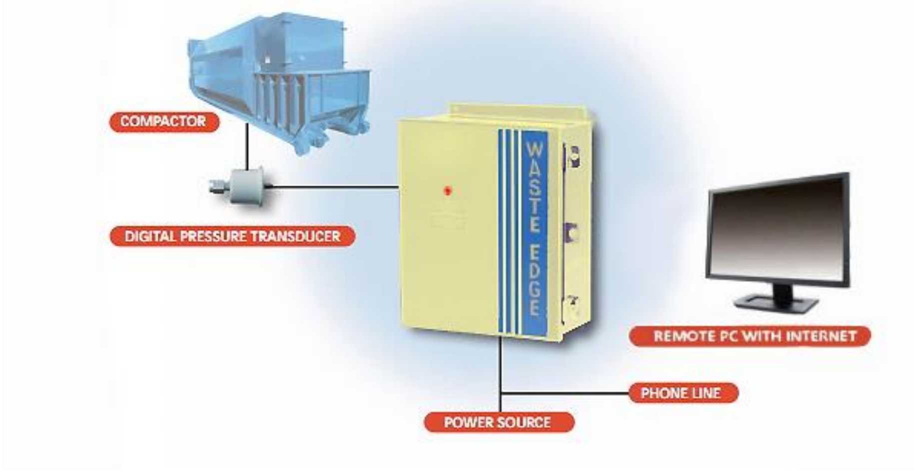

Figure 5. Waste Edge monitors alert waste haulers when they are nearly full, so they can be collected as-needed.

Installing monitoring systems to save money and energy on waste hauls will show that even waste should be considered for making an impact. Adding a monitoring device to campus compactors will reduce carbon emissions. Currently, compactors are hauled from UMass three times per week on a schedule and are typically only 38-63% full [4]. Wireless Waste Edge Monitors measure the fullness of the compactors and automatically alert haulers when the units are 80% full (Figure 5). With this system, the efficiency of removal would be increased by at least 17%. This increased efficiency allows for one less collection of each compactor every two weeks. One less collection sounds small, but over time the environmental savings lead to significant results. Burning a gallon of diesel fuel releases 23 pounds of CO_2 [20], and a typical trash vehicle averages 2.5 miles per gallon [21]. Hauling every compactor on campus to its disposal site a single time equates to 3,208 pounds of emitted CO_2. Assuming that the monitoring systems will reduce one haul every other week, 25,660 pounds of CO_2 (the weight of 33 grand pianos) could be saved in a 16-week semester. Trash monitoring devices may thus provide positive environmental impacts on campus waste management.

A waste monitoring system would consume energy, but the energy savings would greatly offset the system's small resulting power requirement [7,4,18,19,21]. The monitoring system requires 0.12 kWh of energy per day [7]. However, one haul consumes 60 gallons of diesel fuel [21]. One gallon of diesel is equivalent to 37.2 kWh (based on diesel energy density). Each saved haul would result in a savings of 2,270 kWh [18]. Therefore, 33,471 kWh (from all 15 compactors on campus) would be saved every two weeks [4,18]. Yearly energy savings (870,250 kWh) could power the average American household for 20 years (accounting for a 25% conversion efficiency of engines) [19]. The monitoring systems' 3,000-fold energy savings make them quite attractive for the UMass campus.

Monitoring systems can provide a steep return on investment. UMass pays \$2.85 per mile for each waste haul [4]. Assuming three collections per compactor each week, this price amounts to \$3,064 to haul all 15 compactors. When hauled, compactors typically contain only 3-5 tons (out of their 8-ton capacity) [4]. If the monitoring devices allowed these compactors to be hauled at 80% capacity (6.4 tons), they would only need to be collected five times in two weeks, rather than six. One less pickup would save UMass \$1,021 every other week [4]. The cost of a waste monitor is \$3,673 [34]. Knowing there are seven monitoring systems already on campus (but not utilized), adding eight more would cost \$29,384. This large price would be paid off in 58 weeks, therefore UMass would start yielding a profit off of the monitors in the beginning of the second year.

The monitoring unit would be simple to install, but changing the current waste collection system could pose challenges. The installation of these monitoring systems will require permission from UMass waste management. If a monitoring system were implemented, switching from scheduled pick-ups to as-needed pick-ups, Wickles Trucking would lose money from making fewer trips. Additionally, being on-call would be difficult for the trucking company and weekend collections would be problematic due to waste disposal sites being closed [4]. At first, an arbitrary schedule may be inconvenient for Wickles, but eventually collection patterns could be observed from the monitors' data and a more regular (and efficient) schedule could be developed. Despite the fact that Wickles might lose money, the energy, and environmental benefits will be worth it.

Adding monitoring systems onto waste compactors at UMass campus will reduce trash vehicle carbon emissions, save energy by reducing consumed gallons of diesel fuel, and lower expenses for the university. Waste Edge monitoring systems require no additional land area or alteration to the landscape. The monitoring systems R.O.I. is less than a year, meaning that ⅘ of the SIEF funding period could be spent returning money to the fund and promoting other sustainable projects on campus.

7. Conclusion

UMass Amherst should invest in waste monitoring systems to enhance its sustainability. As a large campus with a large carbon footprint, the University must continue to reduce its environmental impact. Approximately five tons of CO_2 (a greenhouse gas) are released every week from waste compactor collection on campus alone [21]. In the year 2013, approximately 82% of greenhouse gas emissions (which contribute to global warming) came from CO_2 [35]. With this fact in mind, it is important to drastically cut down on emissions as quickly as possible. Waste monitoring systems could potentially reduce campus' compactor collection emissions by one-third; this equates to reducing up to 3,200 pounds of CO_2 gas emissions every week [21]. Generally, economic factors play a dominant role in deciding how to solve environmental problems. The cost constraint of the Sustainability, Innovation and Engagement Fund will not be an issue for the waste monitoring systems. By reducing the university's number of weekly waste collections, the monitoring systems save enough money to pay themselves off in less than a year. Although the total initial cost is above the SIEF budget, it would be relatively simple to install the monitors in tiers. By purchasing three monitors per year, the university would be able to fully enact this plan within the SIEF's five year return on investment requirement. In addition to being affordable and reducing harmful carbon emissions, these monitors can conserve considerable amounts of energy. Waste collection vehicles burn diesel fuel and get very low gas mileage, which is why cutting down the driving distance is a notable benefit of the monitors. On a yearly basis, the monitors can save enough energy from diesel fuel to power the average American household for 40 years [19]. Given that UMass has high sustainability goals, effort should be put into altering the current waste management system to better fit these goals. "Cleaning up" campus' current waste management system with Waste Edge monitors will demonstrate how simple changes can have a substantial impact.

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