Waste Characterization and Reduction for the ChE 460 Laboratory Course

Honors Capstone Project Report

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EXECUTIVE SUMMARY

Lab waste in the ChE 460 lab course at the University of Michigan was audited for three weeks, in which changes to protocol were piloted in the third week of the audit. Focused on reducing waste, these changes are feasible and recommended to utilize for other lab spaces. The changes put in place for two of the seven ChE 460 experiments resulted in approximately 30% reduced waste by weight, and have associated cost savings of about $350 total per semester. This lab course operates at full capacity every semester, increasing the amount of impact this project has on the university. Additional audits can be performed on the remaining experiments of this lab for even more opportunity to reduce waste. Many of the recommendations created in this project are transferable for other similar lab spaces. A broader list of waste-reducing considerations was also generated for use in spaces beyond campus labs.

The recommendations implemented in the third week of the audit are focused on reducing the use of single-use disposable products, reusing materials when possible, and decreasing the amount of hazardous waste generated. The participating students showed great effort in adhering to the protocol changes and proved the feasibility of the implementation. For example, in week three, more glass centrifuge tubes were cleaned and reused as an alternative to plastic conical tubes. Syringes were used multiple times as appropriate before sending to waste, and the amount of solvent used to clean the lab equipment after each trial was cut in half. In a brief feedback survey, most students said these changes did not add significantly more time or effort to their lab period and that they would adhere to similar changes in the future.

Waste audits prove very useful for understanding the waste streams of an organization. Not only does it provide data to refer to when setting goals in terms of waste, but it also reveals if waste is being sent to its appropriate disposal. Throughout the first week of the waste audit, it became clear that not all PBR groups were correctly disposing of their waste, placing most, if not all of their solid waste in hazardous waste buckets. After some direct communication with those groups, there was improvement in waste placement. Hazardous waste needs to be properly treated, which incurs additional fees for waste management. Costs can add up quickly if items that could be placed in general waste are placed in hazardous waste buckets. Once an item is placed in hazardous waste, it becomes hazardous and cannot be diverted. Lastly, waste audits can help an organization calculate their environmental impact. Revealing how much waste is being sent directly to landfill can start conversations about waste reduction and combating climate change.

INTRODUCTION

Solid waste that is sent to landfills is a large contribution to climate change and global warming. In 2009, the EPA found that the life cycle of material goods contributes to more than 40 percent U.S. GreenHouse Gas (GHG) emissions [1]. Sustainability practices are more prevalent now than ever and it is up to us to take action on them. The University of Michigan prides itself on its well-established programs for sustainability; however, there is a lot more work to be done to reach the 2025 sustainability goals. The Office of Sustainability has targeted a 40% reduction in waste sent to landfills by 2025, and as of 2022, the university has achieved a reduction of about 13% [2]. Additional efforts are needed, in addition to the waste reduction programs in place, to achieve this goal.

As a Chemical Engineering student at the University of Michigan, I have taken courses with in-person lab experiments and have witnessed first-hand the substantial quantity of waste generated from labs alone. For lab spaces in particular the Office of Sustainability, partnered with the Office of Environment, Health & Safety, have developed a system for reusing and repurposing lab equipment and chemicals to reduce waste. This system is called the ChEM Reuse Program [3]. This is a great first step to create a communal supply of materials for labs on campus to prevent sending more unnecessary waste to landfills. To contribute to waste reduction in university lab spaces, I took a closer look at one of the Chemical Engineering lab courses (ChE 460) by auditing its waste and making adjustments to experimental protocol to reduce waste. Although this project has a relatively small scope, it will provide results that show the feasibility of reducing waste over just a 3-week timespan.

Skills and experiences learned in this process are transferable to other labs on campus, and will encourage more action towards waste reduction overall. Generalized recommendations and considerations can be applied to non-lab spaces, as well as facilities beyond campus. An important goal of this project is to reach more audiences with the data presented to show what is possible. If more universal changes to waste disposal are implemented beyond campus, the world would become more sustainable and the impacts of global warming and climate change would be dramatically reduced.

BACKGROUND

Waste audits provide a space where improvement is encouraged and ambition is challenged by goal setting. For the waste audit I performed, I focused on two of the seven experiments in ChE 460, which are described in more detail below.

Why Waste Audits?

An effective way to quantify the amounts and types of waste being generated by a process is to perform a waste audit [4]. Waste audits can also identify current waste practices and how they can be improved. If the majority of a waste stream is recyclable and being sent to landfill, this scenario may warrant additional efforts for recycling education or refining the company's waste program [5]. The results of an audit can be utilized to form a goal for reducing or diverting waste for an organization, from which future audits would be compared. Waste audits can also influence purchasing decisions. Companies may look for take-back programs to maximize material usage or reduced packaging options when applicable [5]. Lastly, audits are utilized to measure environmental impact. Visualizing and analyzing waste data alone can have an impact on reducing one's environmental footprint.

Photobioreactor: Cultivation of Microalgae for use in Biofuel Production

The photobioreactor (PBR) used in ChE 460 consists of six vertical glass tubes containing algae and necessary nutrients for algal growth. The purpose of this experiment in rotation two is to determine the optimal concentrations of nutrients, nitrates and glycerol, to add to the system to optimize algal growth and lipid production. The lab protocol requires students to monitor pH and run algae samples to determine the concentration of algae, nitrates, glycerol, and lipids over time [6]. To prevent contamination across samples, many different sample tubes and pipet tips must be used. It is already a requirement to use reusable glass centrifuge tubes and clean them after experimentation is complete.

Transesterification Reactor: Pilot-scale reactor for Biodiesel Production

The Reactor station is set up like a mini pilot-scale plant. The 500mL batch reactor was agitated, and a constant temperature was maintained using a reactor jacket [6]. The transesterification reaction is a key step in producing biodiesel from plant oils, in this case, soybean oil. Rotation two's main objective was to determine the optimal operating conditions to achieve the highest conversion and yield. The reactor was sampled frequently via a sample port and disposable syringes. Between trials, the reactor must be cleaned thoroughly with solvent.

METHODS

A daily waste audit was performed on two of the seven 460 experiments, Photobioreactor (PBR) and Transesterification reactor (Reactor) over rotation two of the course. Each rotation is three weeks long and there are four active lab days every week. Waste receptacles were checked prior to the first lab day of the week, and waste was collected, sorted, and weighed after each lab day. Hazardous waste jugs and buckets were weighed using a bathroom scale and the items within the buckets were counted within the bucket itself using appropriate personal protection equipment (PPE). General waste was sorted and characterized using a large tarp and nitrile gloves. The trash bags used in the lab were difficult to effectively weigh given their large size relative to the scale used, therefore the bag itself was assumed to have a negligible weight. Each item recorded via the audit that was used in one of these experiments was weighed using a lab bench scale to measure total reduced weight before and after implementation. The cost of each item was also collected, with the assistance of the ChE 460 lab coordinator, to calculate the amount of savings associated with the changes.

Waste Diversion and Appropriate Disposal

Throughout the first week of the waste audit, I quickly noticed that not all PBR groups were correctly disposing of their waste, placing most, if not all of their solid waste in hazardous waste buckets. Microalgae and its nutrients for growth are not hazardous substances and can be placed in the general waste bin. Because of this error, I reached out to each team leader for rotation two in efforts to record an appropriate waste audit the following week. This communication showed improvement in waste placement in weeks two and three. One can not depend on the waste depositor's behavior for appropriate waste disposal. Additionally, hazardous waste needs to be properly treated, which incurs additional fees for waste management. Costs can add up quickly if items that could be placed in general waste are placed in hazardous waste buckets. Once an item is placed in hazardous waste, it becomes hazardous and cannot be diverted.

An unexpected component of this process was the participants' failure to divert waste. Waste diversion, or landfill diversion, is the process of diverting waste from landfills by recycling, reusing, composting, etc. [7]. Although the majority of the lab waste is contaminated and needs to be sent to landfill, there were some items in the general waste bins that could have been recycled. Most lab spaces do not hold recycling bins in the lab due to the risk of the lab user disposing of something hazardous or non recyclable in the recycling bin. Again, the lab user's behavior is out of the control of waste management.

Data Analysis

The daily count of each item used in the PBR and Reactor experiments was averaged over the first two weeks of data to represent waste amounts "Before Implementation". Week three data was also averaged and it represents "After Implementation". It was assumed that waste associated with the PBR and Reactor experiments was contained in the general waste bins near the PBR station and Reactor station, respectively. Manipulation of PBR waste was mostly focused on solid disposable waste, and that of Reactor was focused on both solid hazardous waste and liquid hazardous waste.

The PBR protocol was mostly consistent for each day of the week, therefore the waste audited for PBR did not vary significantly by day. However, the reactor experiment is trial-based and can be more variable in the audit on a daily basis. I obtained each group's breakdown of reactor trials for rotation two in order to calculate the waste generation on a trial basis. There were 12 trials performed per week, on average. For extrapolated cost and weight estimates, it was assumed an average of 12 trials per week. Due to large amounts of solvent used to clean the reactor, I assumed a ratio of 2:1 Methanol to Isopropyl Alcohol (IPA) for the make-up of the hazardous waste jug at the reactor station. Methanol is also used as a reactant in excess for the transesterification reaction itself, providing more confidence of a high methanol content in the liquid waste jugs.

RESULTS

The recommendations generated below were provided to students in week 3 via a Management of Change (MOC) to their lab protocol. This format, approved and delivered by the lab supervisor Dr. Barr, helped to present it as a credible and reliable list of changes to consider for the last week of experimentation.

Piloted Protocol Modifications

The following recommendations were provided for the participating students for week 3 of the rotation. I consulted with the students each day of this week to answer any questions about the changes to their protocol.

Photobioreactor

1. **Keep using the same 60 mL syringes and do not dispose of them**, unless they break. The Monday team is responsible for keeping the syringes screwed on the PBR for the remaining days.
2. **Use reusable 10 mL glass centrifuge tubes** when performing a serial dilution. This may not be possible with samples containing supernatants that need the use of a syringe. The 10mL syringes are too wide to fit into the 10mL glass centrifuge tubes.
3. **Use the same pipet tip/syringe for dilutions of the same PBR tube** when performing a serial dilution. For example, use 1 pipet tip using a micropipette for all dilutions for PBR tube 3. Do not use the same pipet across tubes to prevent contamination in your samples.
4. **Determine if cuvettes could be rinsed with ethanol and reused** upon completion of measuring absorbance. After disposing of the diluted algae from the cuvette, carefully examine it for scratches and rinse with ethanol. Place reused cuvettes in the appropriate labeled container.
5. **Eliminate the usage of tape on your sample tubes.** Sharpies can be used to write your sample ID directly on the tube.

Transesterification Reactor

1. **Minimize the usage of tape on vials**. One group from Week 2 proved it possible to write directly on the vial with Sharpie.
2. **Use the same 1mL syringe to pull samples.** This should be done by quickly pulling samples up and down into the syringe three times to “rinse” the syringe before pulling the sample.
3. **Use less solvent to clean the reactor.** Try using ½ the volume of IPA/Methanol for cleaning the reactor vessel. To do this, use 150mL compared to the alternative 300mL for cleaning.

Photobioreactor Results

Photobioreactor waste was categorized into gloves, paper towels, pipets, syringes, cuvettes, filters, and miscellaneous. The pipet category contains micropipette tips, serological pipets, and 7mL disposable pipets. Syringes include both 60mL and 10mL syringes, and the miscellaneous category accounts for additional disposable waste like conical tubes and kimwipes. The effect of implementation in week 3 is displayed in Figure 1 below. The total items counted decreased by 58% from 214 to 124 items. The biggest difference in count is seen in the miscellaneous category. The recommendations encouraged the students to reuse glass tubes to perform serial dilutions rather than using disposable conical tubes. However, the number of kimwipes, which were also categorized as miscellaneous, did not vary much between weeks.

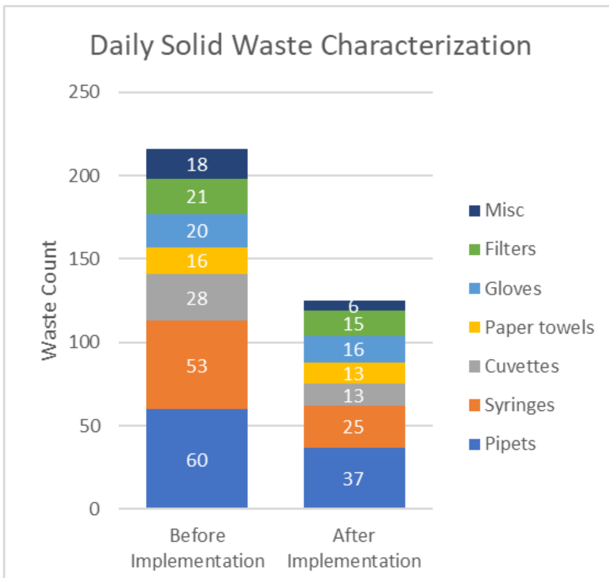
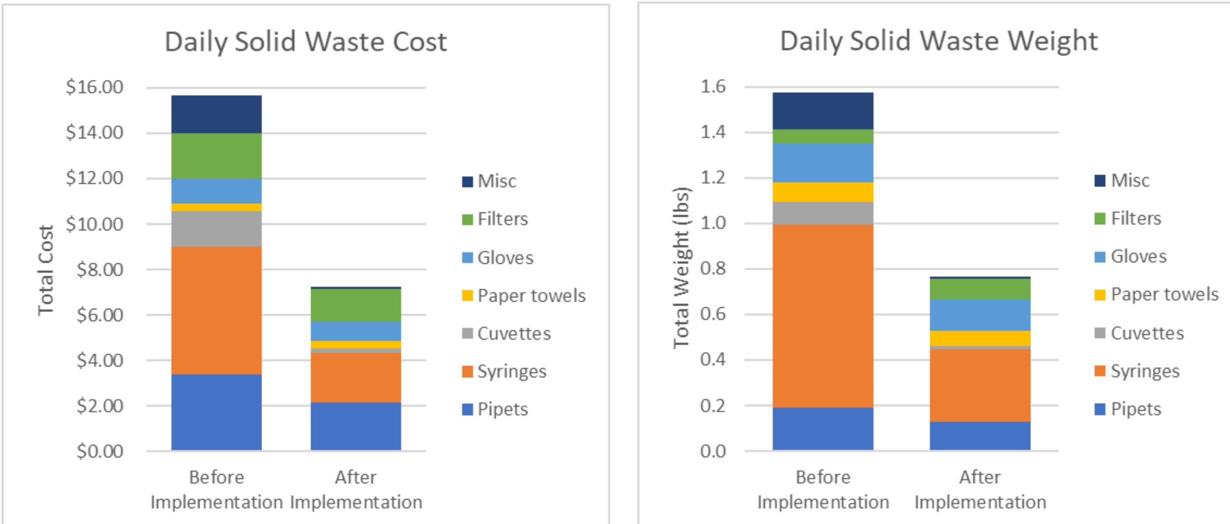


Figure 1. Photobioreactor solid waste before and after implementation.

The decrease in the amount of waste after implementation for PBR is highlighted again in Figure 2 below, given each item's respective cost and weight. The most expensive items for the PBR experiment are the 60mL syringes and 50mL plastic conical tubes at $0.49 and $0.15 each, respectively. The amount of 60mL syringes were decreased by about 70% by reusing them each lab day, and there were no 50mL conical tubes used in the third week of experimentation, seeing the potential of completely eliminating an unnecessary item. Total cost savings upon implementing the changes to the PBR protocol was estimated to be $8.40 per day and $33.60 per week.



(a) (b)

Figure 2. Photobioreactor cost savings and waste reduction before and after implementation.

Similarly, the two items that weigh the most in this audit are 60mL syringes and 50mL conical tubes at weights of 0.074 lb and 0.028 lb, respectively. Weight of waste decreased by about 50%. Total waste reduction in weight upon implementing the changes to the PBR protocol was estimated to be 0.81 lb per day and 3.24 lb per week.

Transesterification Reactor Results

Reactor waste was characterized into gloves, paper towels, pipets, syringes, vials, and solvent (liquid). The pipets category contains both 200μm and 1mL micropipette tips, the syringes contain 1mL syringes, and vials being mostly 4mL glass vials filled with chemicals used in sample preparation and 2mL glass vials used for samples to be analyzed in additional lab equipment.

Solid waste, on a reactor trial basis, before and after implementation is shown below in Figure 3. There is less variation in the amount of materials used with changes to the protocol because most groups used similar amounts of each item for each trial they performed on the reactor. However, the biggest improvement for the reactor in terms of solid waste is the decrease in the amount of 1mL syringes used to take samples from the reactor. With the lab supervisor's approval, groups could reuse the sample syringes as long as they followed the protocol and flushed the syringe properly before each sample. However, taking samples from the reactor is a quick and intense process for lab users. All groups found themselves using more than one syringe for each trial because they would not have enough time to dispense the syringes before prepping for the next sample. Despite the challenges, all groups managed to significantly decrease the amount of syringes they used in week 3, the smallest amount used per trial being 4 syringes.

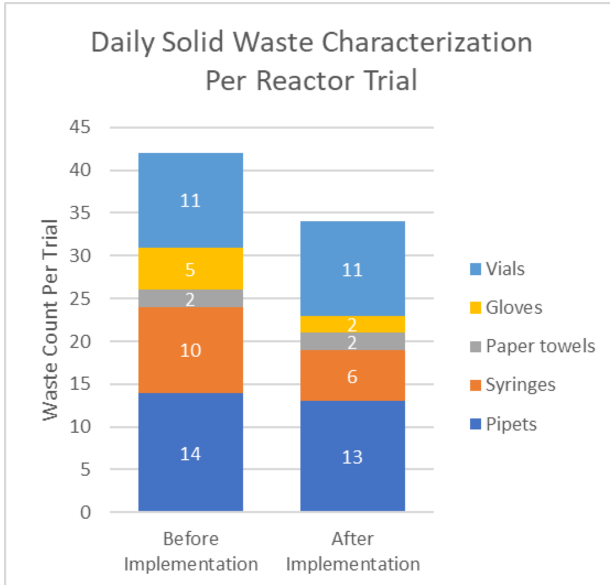


Figure 3. Reactor solid waste characterization before and after implementation (on a reactor trial basis).

As seen below in Figure 4, reactor solid and liquid (solvent) waste was priced and weighed to give desired results. The heaviest and most costly solid materials for this experiment are the 4mL vials at $0.710 and 0.019 lb each. Methanol is priced at $1.51 per lb, and IPA is priced at $4.93 per lb. Cutting the solvent use by half to clean the reactor had the biggest impact on both cost and weight with about 13% and 22% total reduction, respectively.

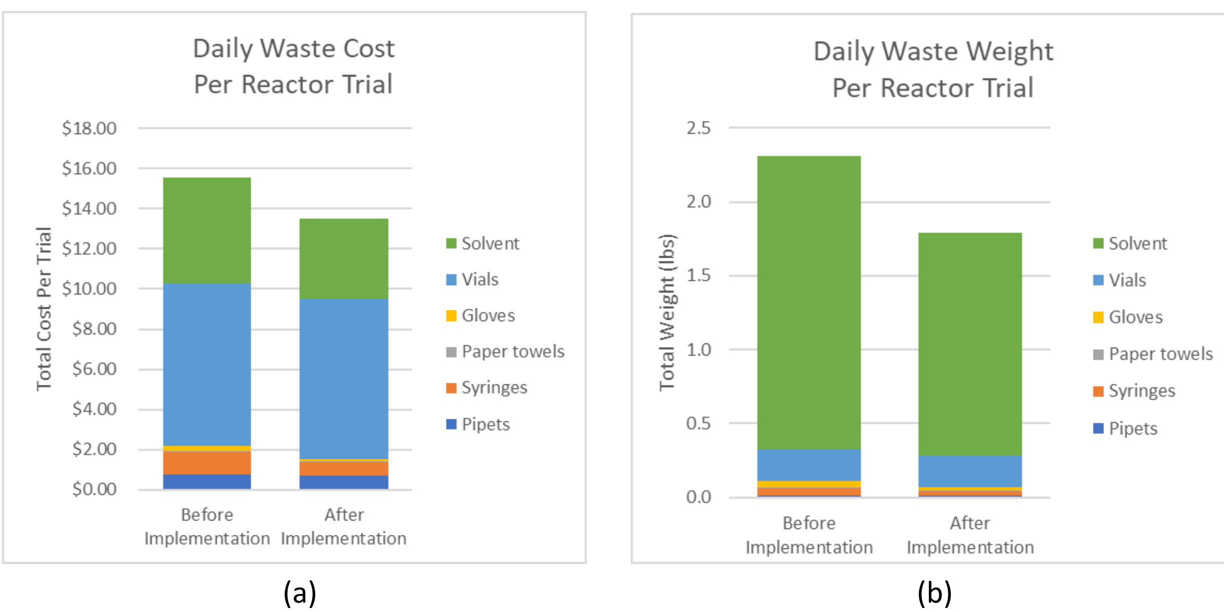


Figure 4. Reactor cost savings and weight reduction before and after implementation (on a reactor trial basis)

CONCLUSION

The opportunity to audit the waste of a lab in the chemical engineering department gave me insight to what may be possible for the rest of campus. Implementing some changes to lab protocol resulted in approximately 30% reduced waste by weight, and associated cost savings of about $350 total per semester. ChE 460 operates at full capacity every semester, increasing the amount of impact this project has on the university.

Future Considerations

Upon completion of this project, I wanted to create a broader list of recommendations that are more transferrable to other labs on campus. Below are some general tips for reducing waste to consider in other environments.

1. **Utilize reusable glassware and replace disposable plastic items with reusable alternatives when possible.**
2. **Maximize the use out of disposable materials before disposal.***
3. **Use non-sterile options for syringes and filters if possible.** Sterile items require additional packaging that is sent to waste.*
4. **Minimize the usage of solvent and other liquid hazardous waste.** Determine if smaller amounts can give you the same outcome.
5. **Minimize tape usage.** Some tubes are manufactured with designated labeling spaces.
6. **Make available a recycling bin for waste as applicable.** Many audited items were re-sorted into a recycling bin, as necessary.
7. **Set clear guidelines about the amount of each material that can be used in lab and train staff, as necessary.** User behavior is a significant contributor to waste generation.
8. **Perform waste audits!** Visualizing generated lab waste creates a sense of action and accountability, as well as promotes further improvements for waste reduction.

*Be careful to avoid contamination in biological processes. Be mindful of safe practices in the lab (safety comes first).

Waste Awareness and Taking Action

In addition to expanding this project to more of the ChE 460 experiments, there is potential to have great influence on the rest of the university and beyond. Expanding the awareness of waste generation and diversion is critical to limiting the impacts of climate change and global warming. I truly believe that an increase in waste awareness alone has the power to start conversations about what is thrown away, and ultimately influence the decisions people make about waste in their lives.

Sometimes the element that is missing from the equation is not just infrastructure and the materials we use, but education around what one can do with their waste. Waste reduction, in general, may be a difficult task to achieve quickly. Changing human behavior takes time if it is not in a structured environment like the ChE 460 laboratory. However, one can start tackling this problem by considering waste diversion like recycling and composting. The first step to reducing waste is to ensure that people know where to throw and that the system used is accessible.

Participating Student Feedback

A google form was sent to the participating students asking for their thoughts and experiences throughout this project. The first part of the survey asked if the changes to the protocol significantly affected their time and effort for completing the ChE 460 experiments. Out of nine survey respondents, five students claimed there was no difference in the amount of time spent in the lab and five claimed that the changes did not impact the amount of effort required to complete the experiments. On average, PBR groups said slightly more time was required and no change in effort, as opposed to the Reactor groups that experienced both a decrease in time and effort required in the lab.

The second part of the survey displayed the results of the audit and implementation and asked students to comment on if they would be willing to adhere to similar changes in the future. Most students responded that they would be likely to do so. If the other experiments in this course were audited and manipulated in the same way, these lab users would be willing to change their protocol to reduce the amount of materials sent to waste.

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