ENVISIONING SAFE AND SUSTAINABLE LABS WITH HUMAN-CENTERED SYSTEM DESIGN

AN EXPERIMENTAL STUDY ON DISPOSABLE MATERIAL FLOW

Researcher: Sheng-Hung Lee*[a, b, c, d]

Advisor: Dr. Julie Newman [c]

[a] Massachusetts Institute of Technology Integrated Design and Management
[b] Massachusetts Institute of Technology Department of Mechanical Engineering
[c] Massachusetts Institute of Technology Office of Sustainability
[d] Massachusetts Institute of Technology AgeLab

Abstract: *The purpose of the study is to explore disposable laboratory material flow on campus using Human-centered System Design (HCSD). We used Massachusetts Institute of Technology (MIT) campus as a testbed to conduct the experimental study for sustainable innovation. We selected four types of labs: biological, chemical, material, and mechanical engineering, and two makerspaces to interview principal investigators (PI) and shop managers about building safe, sustainable labs. Besides field research and interviews, we launched a survey of lab pipette tip boxes as a case study to have more in-depth material flow information from procurement to disposal. The aim of the study is to refine lab material purchasing, inventory management, recycling and disposal to identify pain points and opportunities to make lab material flow more sustainable and safer on campus.*

Keywords: *Sustainability, Safe, Lab, Material Flow, Human-centered System Design*

1. Introduction

Massachusetts Institute of Technology (MIT) is committed to achieving net-zero emissions by 2026 and eliminate direct campus emissions by 2050. Labs at MIT have collectively used over 65% of campus energy, even though labs only occupy 25% of the physical footprint [1, 2]. In the study, we researched disposable lab material flow as a starting point to envision how to build and run a safe, sustainable laboratory on campus. For the purpose of testing this approach we provide a case study of pipette tip box usage in laboratories. Understanding laboratory material flow is an integral part of this study.

* Corresponding author: Sheng-Hung Lee | e-mail: shdesign@mit.edu

At MIT, faculty and researchers use the latest technologies and research to promote the campus not only as a testbed for sustainable innovation but also as a living lab to enable creating a safe and sustainable blueprint in the most efficient and socially impactful ways. MIT Green Lab Program, initially launched in DATE [3] is a great example demonstrating how the Department of Environmental, Health and Safety collaborates with schools across MIT to enable laboratories to ensure safety first and have established guiding principles, communication channels, collaborative platforms, shared visions, tools, knowledge, and training programs to operate in a sustainable manner.

In this study, we conducted two case studies to collect the first-hand material: 1) field research and initial survey on lab practices: We visited four different types of labs: biological, chemical, material, and mechanical engineering and two campus makerspaces: The Deep and Metropolis. 2) pipette tip box survey: We used pipette tip boxes as a case study to demonstrate the material flow from procurement, to disposal, and recycling in laboratories [4]. Since this is one-year experimental study, we defined this initiative as an entry point for us to understand users' pain points, the challenges of the institute, and how complicated it is to build a safe and sustainable laboratory on campus.

2. Literature review

The study used MIT campus as a case study to research. We emphasized journals, papers, and laboratory reports of disposable laboratory material flows. We also conducted interviews from MIT Office of Sustainability (MITOS), MIT Department of Facilities, MIT Environment, Health & Safety Office (MIT EHS), MIT Office of the Vice President for Finance (MIT VPF), and two makerspaces: The Deep and Metropolis to help define the scope and problems regarding disposable laboratory material flows (Figure 1.).

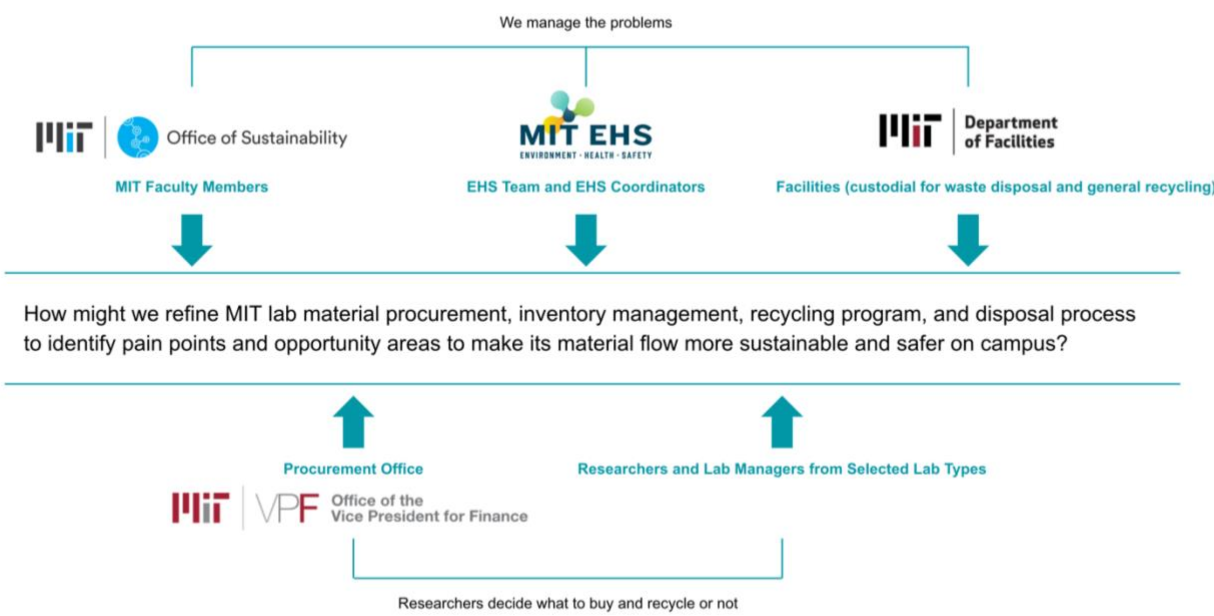

Figure 1. Key stakeholder map

2.1 Disposable laboratory material flow

We categorized a typical disposable laboratory material flow into four phases: procurement, inventory management, recycling and disposal [1]. According to the literature and interviews, we summarized the top five common disposable laboratory items at MIT: nitrile gloves, pipette tips, pipette boxes, centrifuge tubes, and conical test tubes. We used field research and a survey to analyze the disposable material flow of these items from procurement, inventory management, and recycling, to disposal [5]. In the study, we used pipette tip boxes as an experimental case study to demonstrate people's consideration and behavior in relationship with material flow in laboratories.

The concept of a circular makerspace [6], a space with a shared sustainable vision by applying circular design methodologies and human-centered design to achieve carbon neutrality in the environment and system, can also tie to the disposable material flow in laboratories. The ultimate goal is to reduce the material and carbon footprint both in laboratories and makerspaces on campus.

2.2 Human-centered system design (HCSD)

HCSD is a modified research process curated with IDEO's version of design thinking [7] and system engineering [5, 6] to analyze its model. We visualize the journey of disposable laboratory material paired with people's behaver with these materials to discuss the pros and cons among sustainable laboratory material, procurement cost, recycling process, and decision making [11] (Figure 2.). We used HCSD to analyze the disposable laboratory material flow, which is an innovative approach to the study and helped us identify pain points across the design journey [12]. HCSD not only provides us a holistic view of the challenges, but also allows us to change the fidelity and zoom into the target [13].

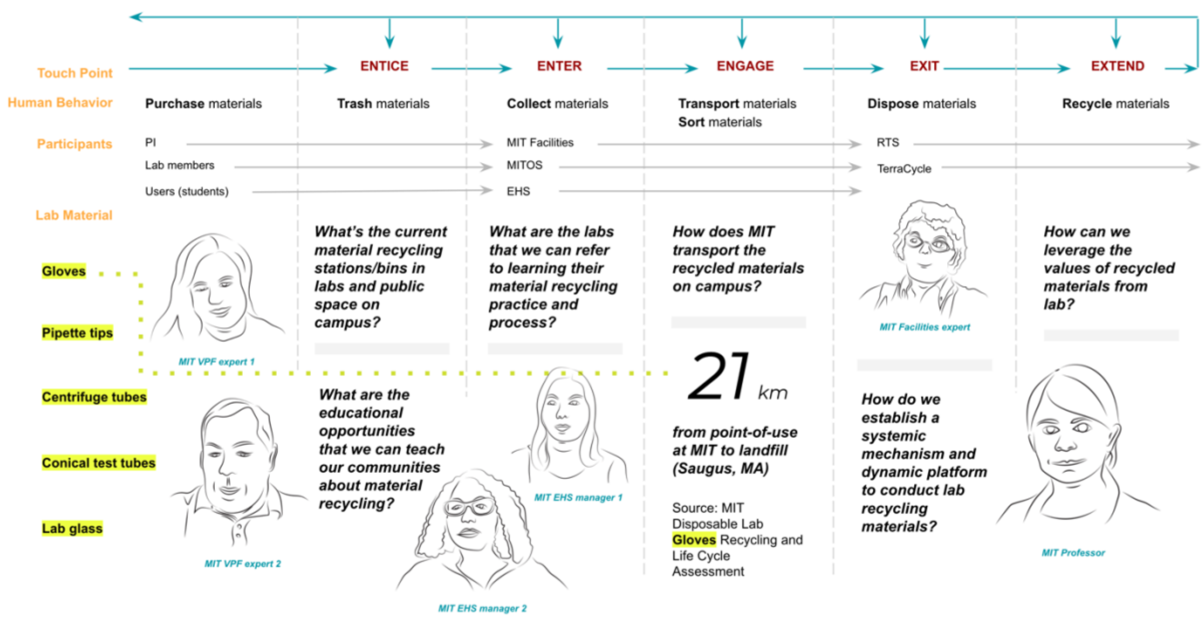

Figure 2. Journey map of disposable laboratory material flow paired with people's behavior and interviewee's questions

3. Experimental research approaches and results

3.1 Case study 1—Conduct field research on laboratories and makerspaces on campus

3.1.1 Preparation—Design and launch survey to lab PI before field research

Before we visited three laboratories and two makerspaces on campus, we wanted to have a preview and learn from the PIs in advance. Therefore, we designed a 10-15 minute survey to share with them two weeks before visiting them separately.

We designed the survey with three types of questions: seven single-choice questions, five multiple-choice questions, and six open-ended questions. Our intention was to briefly understand the current situation in space e.g., laboratories or makerspaces equipment, culture, recycling procedures, sustainable policy or regulations influenced by the institute. We also knew their pain points as users of the space, and also "downloaded" their knowledge around this topic via survey. Table 1 showed the detailed demography of the survey participants. The following sections originated from the survey result that we collected and synthesized.

Table 1. The demography of survey participants (n=5)

Background	Gender
• Principal Investigators (60%)	• Male (60%)
• Lab Manager (20%)	• Female (40%)
• Makerspace Manager (20%)	• Prefer not to say (0%)

- **The tension between the individual and the institution**

As Figure 3 shows, 25% thought waste management was critical and needed institutional support, followed by 20% who viewed material choice (including chemicals) and energy use as important and also needed support from the institute, whereas only 10% thought lab infrastructure was important.

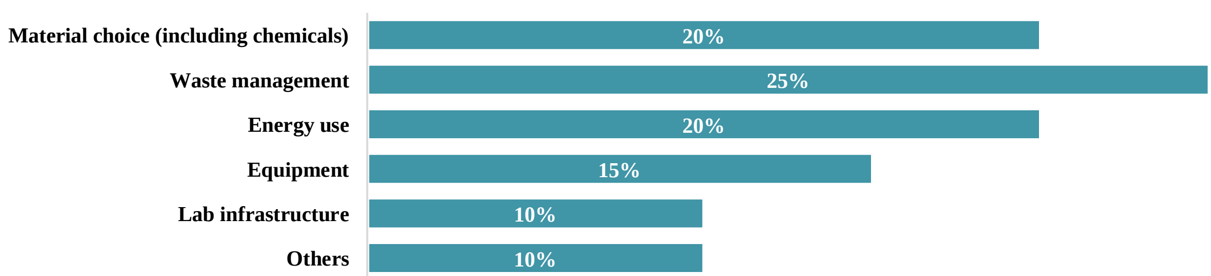

Figure 3. Please indicate which of the following matters would require institutional support for you to implement and which of these could be carried out as an individual lab? Please elaborate if necessary.

Figure 4 shows that 19% thought sustainable material options from vendors and regulated and unregulated waste output would inform and enable them to qualify the sustainable practice/design in their lab; 15% thought the options like airflow, recycled waste, and plug load from lab equipment would enable them. Only 4% mentioned system design.

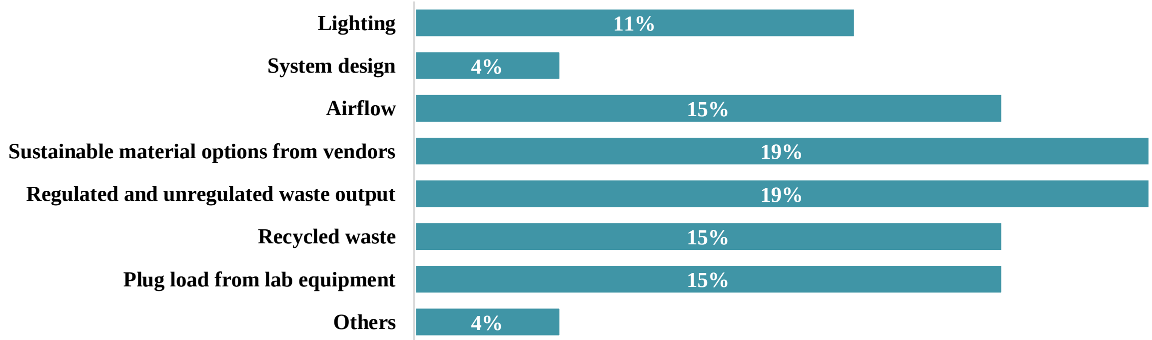

Figure 4. What data will inform and enable us to quantify the sustainability practices/designs in your lab? Select that all. apply.

As Figure 5 shows, unsurprisingly, that 60% needed the support from both institutions and individuals for handling recycled waste. Viewing the whole campus as a system, managing recycled waste was part of the material flow connecting each laboratory to the institutional team responsible to ship them outside to campus. A total of 80% needed the airflow support from the institution, which might be because of the infrastructure that was already built-in in the laboratory.

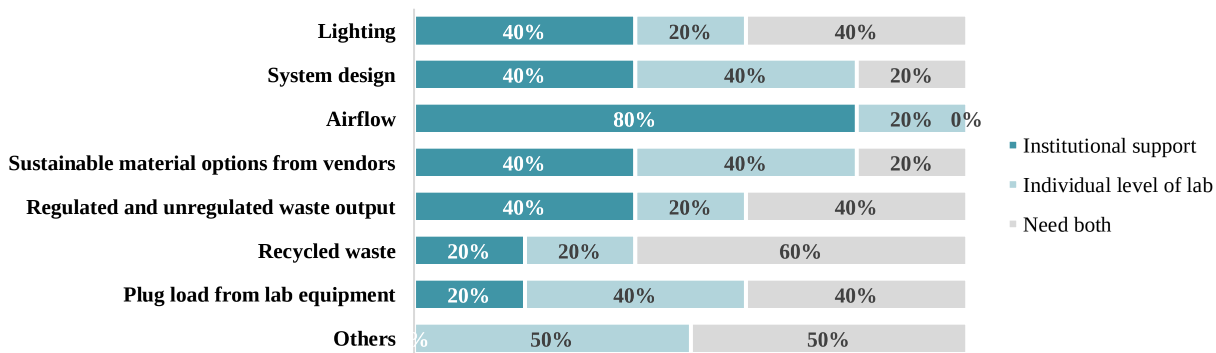

Figure 5. Please share with us whether the following items require institutional support or can be changed at the individual level of your lab, or both.

- **People's purchasing behavior in laboratories and makerspaces**

Figure 6 shows that 80% would consider purchasing sustainable products for their labs. But when we actually assumed that they might need to pay more for sustainable materials, 60% replied maybe. Only 40% wanted to pay more (Figure 7). This can indicate that participants' perceptions of price and value of purchasing sustainable products were different.

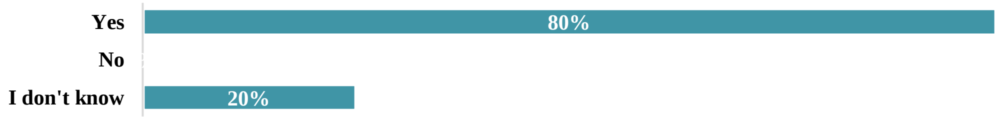

Figure 6. Do you currently procure materials that would be considered 'sustainable'?

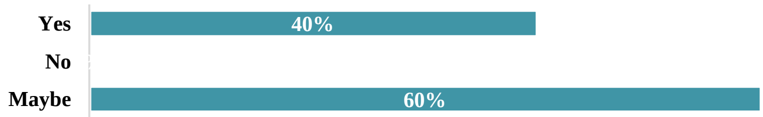

Figure 7. Would you be willing to pay more for sustainable materials?

We were also curious about the participants' procurement behavior. There were different types of laboratories on campus, but they might order similar disposable products e.g., pipette tip boxes, chemicals, or non-disposable materials e.g., machines or equipment. Therefore, we assumed some PIs might purchase materials together, which could save the cost of shipment, labor, and time. Surprisingly, each laboratory made its purchase independently (Figure 8) and we thought this might be due to the design of the institutional purchasing system and the budget of the projects differing from laboratory to laboratory.

Figure 8. Do you currently order material as an individual lab or with others?

- **The material flow in laboratories and makerspaces**

Figure 9, shows that 60% of the PIs were familiar with the current lab material flow/process, which helped us understand how to design a more transparent communication platform in the future, as well as an educational toolkit to facilitate the conversation between the individual e.g., different labs and the institutional e.g., MIT and administration side.

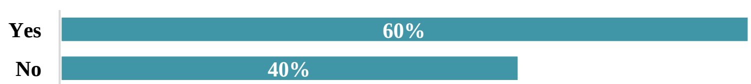

Figure 9. Are you familiar with the current lab material flow/process? For example, where your consumables come from, how they are used, and how they are ultimately disposed of?

As seen in Figure 10, 80% thought regulated waste was less important for material disposal; 40% viewed both non-regulated waste and recyclable material as very important. The result indicated that we might need to place more emphasis on non-regulated waste and recyclable material while discussing material disposal in the context of a laboratory.

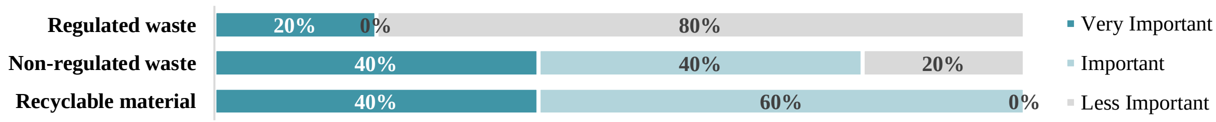

Figure 10. For material disposal, please help us rank order in terms of the level of importance in your lab/shop?

Figure 11 showed that all PIs were willing to brainstorm to solve the current lab waste structure with MITOS, MIT EHS, MIT Department of Facilities, and MIT VPF teams collectively.

Figure 11. Would you be willing to work with us to design out as much of the waste as possible out of the current lab waste structure?

MITOS has already collaborated with Rheaply, an online asset-exchange software company, for three years to help make materials, resources, and even services in laboratories or makerspaces more visible and easier to transfer. Rheaply has modified its interface and platform specifically designed for MIT to adapt to the needs of the institution (e.g., laboratories and makerspaces), students, and faculty members. Even though Rheaply has been embedded in the MIT system for three years, only 40% knew about it (Figure 12).

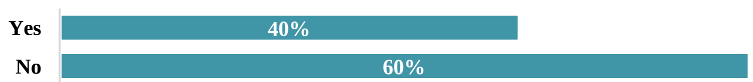

Figure 12. Are you familiar with Rheaply (https://rheaply.com/)?

- **The energy consumption in laboratories and makerspaces**

In building a future safe and sustainable laboratory, we also need to consider the aspect of energy consumption. In Figure 13, the heating and cooling of the lab space, lab ventilation, equipment, and lighting were evenly selected by the PIs. For further studies, we could do a deep dive into the actual energy consumption from each option and compare, since Figure 14 shows that 80% of laboratories did not conduct energy audits and 60% of PIs didn't know whether their laboratories had been optimized their energy used (Figure 15).

Figure 13. What processes consume energy in your lab?

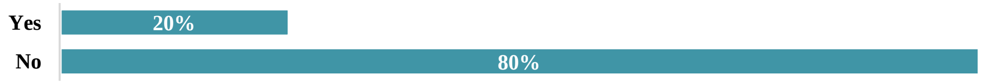

Figure 14. Has an energy audit of your lab taken place?

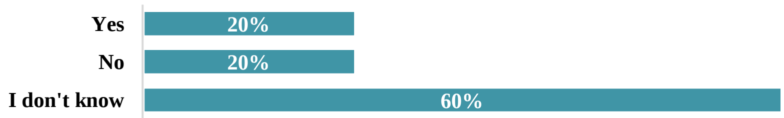

Figure 15. To your knowledge, is energy use optimized in your lab?

Figure 16 and 17 related to energy used in a laboratory. We wanted to understand how PIs and their lab members set up and maintain the same condition e.g., specific ambient temperature, relative humidity, or lighting for their experiments: 40% used sensors to reproduce the environment, for which an automated process could reduce energy use.

Figure 16. Are there specific ambient temperature, relative humidity and/or lighting settings that are necessary to ensure reproducibility of your experiments?

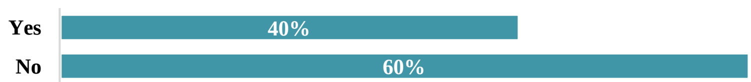

Figure 17. Are there automated processes through sensors (e.g. for lighting) in place to reduce energy use in your lab?

Besides applying automated processes through sensors in laboratories, 40% of PIs and their lab members conducted user-driven energy-efficiency efforts in laboratories (Figure 18). In further studies, we want to know what are the key considerations for PIs selecting between the two systems and their efficiency respectively.

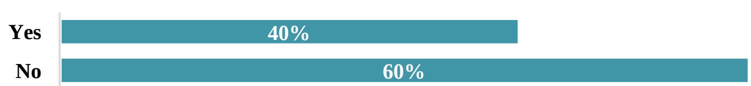

Figure 18. Are lab members currently conducting user-driven energy efficiency efforts in your lab?

- **The key stakeholders' responsibilities in laboratories and makerspaces**

Figure 19 showed the key stakeholders' roles and responsivities in terms of handling energy-related questions in laboratories. For a next step, we can extend this question to analyze the laboratories' structure and how it influences the lab members' behaviors, decision-making process, and safe and sustainable culture.

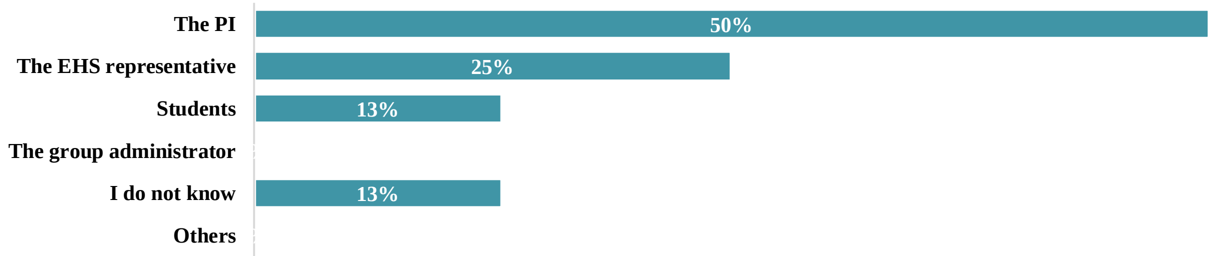

Figure 19. Who handles questions related to energy use in your lab?

We used the above 17 survey questions as preparation material for both our research team and PIs, lab managers, and makerspace managers before we conducted 2-week on-site research. This gave us a great reference to synthesize the on-site observations and people's stories from the field research.

3.1.2 Field research—Visit laboratories and makerspaces on campus

To get the first-hand information from campus, we filtered out three laboratories and two makerspaces out of MIT research units/departments to help us capture survey data, listen to people's stories, and document their pain points. The field research of laboratories and makerspaces was conducted in three-week period during summer 2021, following the MIT pandemic protocol.

When we visited four types of laboratories (biological, chemical, material, and mechanical engineering), purposely observing common challenges and opportunities between four types of laboratories and two makerspaces. For example, over-purchasing disposable materials, lacking an organized laboratory procurement and material tracking system, the incentives of using sustainable products versus the ratio of cost and value, and the communication between laboratories and institutions needs to be more transparent considering the efficiency of decentralized institute's system. We summarized these common problems and developed a hypothetical assumption: these common problems might originate from user behavior (e.g., laboratory culture and life ritual), the institute's environment (e.g., physical and policy), and the tradeoff of using sustainable products (e.g., product cost and time cost).

One professor from the department of civil engineering shared how her laboratory re-designed the flow of a pipette tip box recycling to optimize the life cycle of the disposable product in general (Figure 20). What impressed us was how her laboratory built a flexible-yet-rigorous recycling system based on their previous experimental experience and knowledge to make scientists or graduate students who just join the laboratory understand clear principles to follow and double check the system if anything goes wrong.

At another two laboratories, we visited the professors who focused on the material-and-mechanical-engineering-related research. They also set up their own "laboratory ritual" such as using different colors of tapes as a name tag for each lab member to make a clear responsibility for who owns which equipment. They also created an internal "student on duty" system to allocate laboratory members to have a set time to task to maintain laboratories and manage the emergency situations.

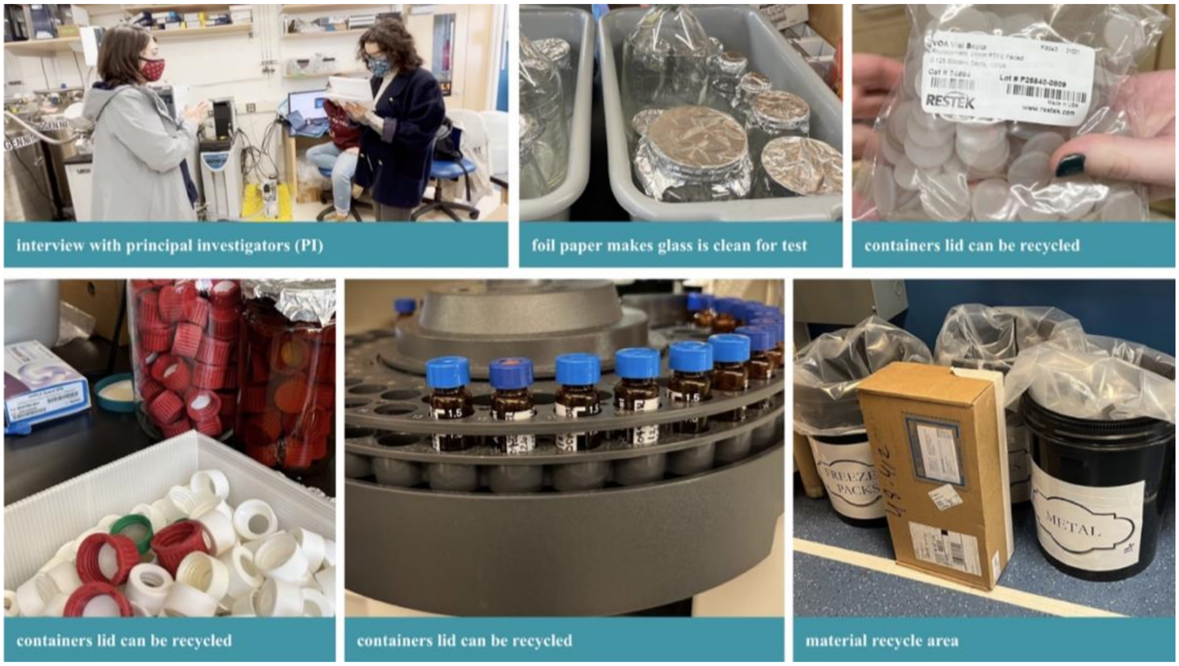

Figure 20. Field research at MIT civil and environmental engineering laboratory to interview the PI.

In addition to visiting the laboratories, we collaborated with the leadership team from MIT Project Manus, committed to upgrading makerspaces and cultivate stronger maker communities on campus [18]. Two makerspaces were selected for review : The Deep and Metropolis. The Deep makerspace offers milling, turning, SLA 3D printing, mold making, and small screen printing, whereas Metropolis makerspace contains welding, laser cutting, FDM 3D printing, basic electronics, sewing, and waterjet (Figure 21).

The makerspace manager organizes their waste material following the guidelines provided by the institute recycling program. Both makerspaces are designed with detailed way-finding systems not only navigating people in the space, but also creating signage for each piece of equipment/machine, so that makerspace members or first-time users can easily know how to safely use or even “master” the machines instantly.

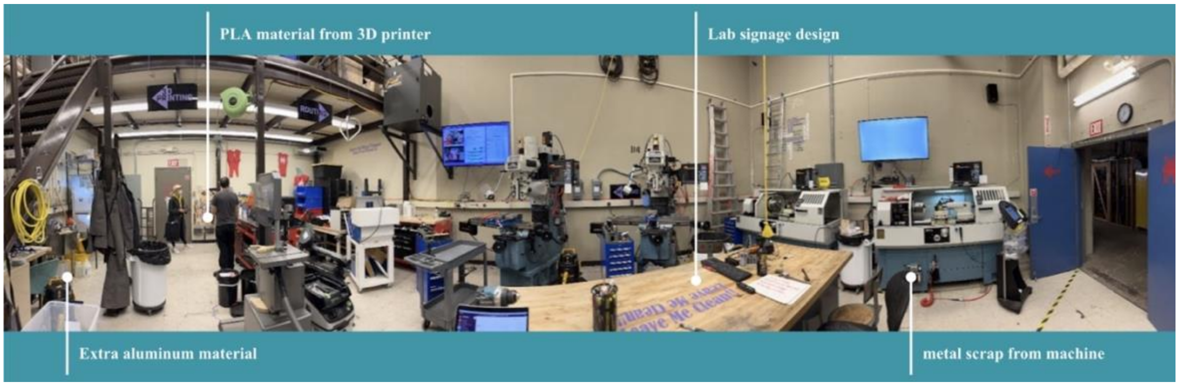

Figure 21. Field research at MIT The Deep makerspace—1

During the tour, we specifically focused on questions around the disposable material flow. The makerspace managers showed us where they stored metal scrap (e.g., aluminum), built an area for material recycling (e.g., acrylic, cardboard, wood), and designated a place for trash (Figure 22). They also demonstrated that 3D printing is a very popular prototyping method among students, however the waste of PLA filament generated by 3D printers is difficult to recycle or is non-recyclable. Some 3D printing companies provide filament recycling services, but most don't have the awareness or service/business model to support the concept of sustainable printing.

One shop manager relayed concern regarding sustainable practices at MIT and stated, "I want to know how the institute or MIT EHS team recycles the disposable material such as cardboard, acrylic, and wood, because I am curious to know where the material goes? If I know the recycling process or at least the next step, I can have a better sense of how I can improve the recycle protocol of makerspace better and more efficient." It informed us the importance of transparency of the material flow on campus both in laboratories and makerspaces. Thus, it has become one of our focuses within our scope of research.

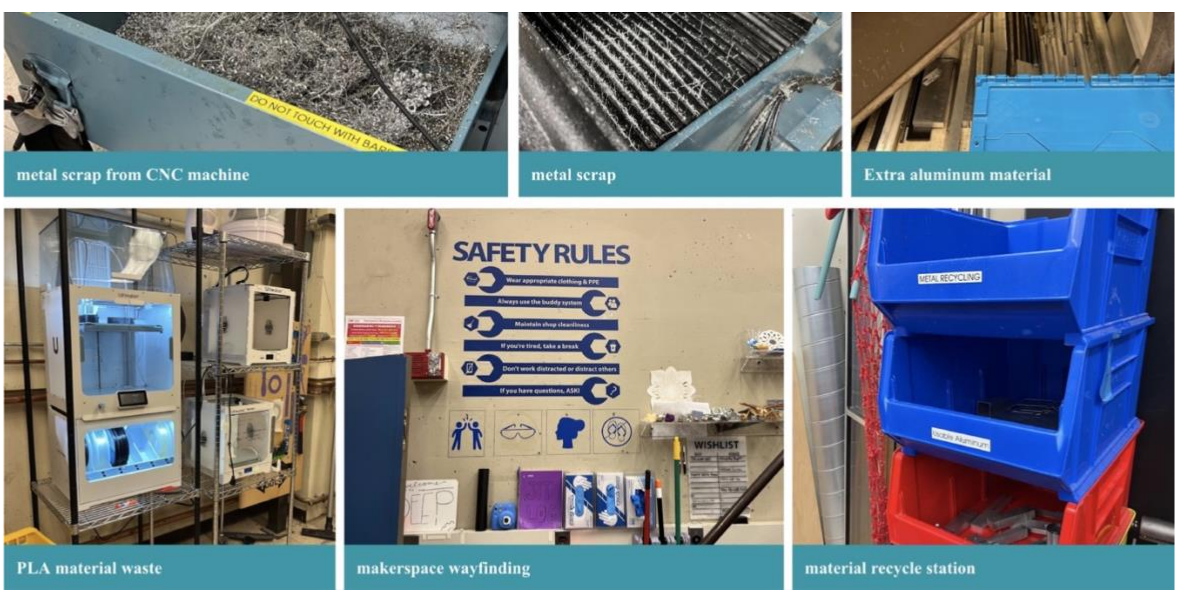

Figure 22. Field research at MIT The Deep makerspace—2

3.2 Case study 2—Reduces plastic waste of pipette tip boxes

3.2.1 Overview—Understand the challenge of recycling pipette tip boxes

In laboratories, we found that pipette tips and boxes take around 80% of laboratory plastic waste from MIT waste audit [15]. Pipette tip boxes are one of the largest sources of laboratory plastic waste (Figure 23) and for this reason, we include a focus on Pipette tip boxes as a case example. With this in mind, we investigated potential opportunity areas of recycling pipette tip boxes in laboratories. Research from UCSB Sustainability indicated that to reduce the waste of pipette tip boxes in laboratories, we had three strategies to consider: 1) plastic reduction strategies 2) choosing recyclable plastics and 3) selecting components that use less disposable material [16].

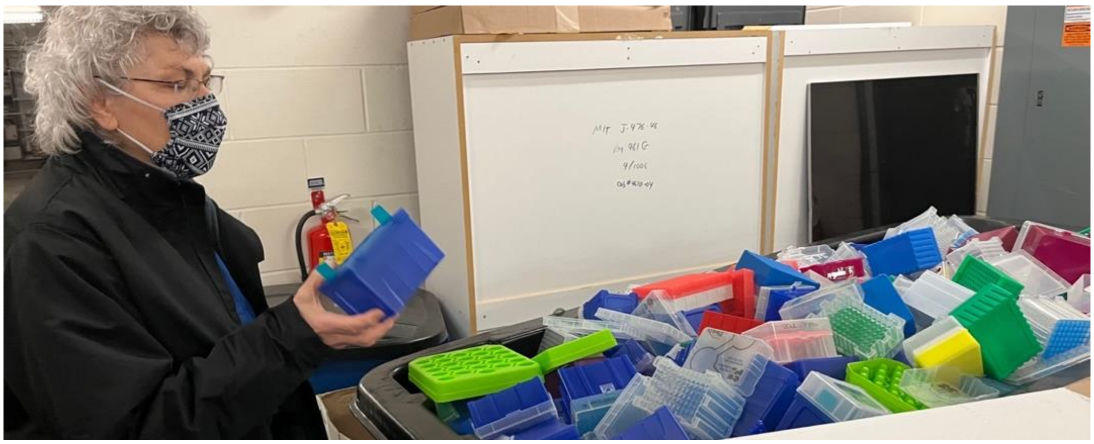

Figure 23. Conducted field research at MIT Building 66 (Landau Building) to observe the large volume of wasted pipette tip boxes from laboratories.

To inform our analysis, we looked to research authored by Tiffany Fierros from the University of California Santa Barbara (UCSB) Sustainability. She described in her research article that the first point, plastic reduction strategies, could mean using stackable racks since their modular design makes them more flexible for laboratories based on people's needs in terms of volume. Also, one stackable tower of racks needs only one plastic cover. People needed to know to leverage the rack refill systems to refill pipette tips without accumulating tips boxes in laboratories and purchase bagged tips to save more plastic containers.

Regarding the second point, choosing recyclable plastic, Fierros suggested that people need to be mindful of the type of plastic they purchase. For plastic recycling in the United States, it accepts polyethylene (PET, plastic #1), polyethylene terephthalate (PETE, plastic #1), or high-density polyethylene (HDPE, plastic #2).

The last point, selecting components that are made of less disposable material, might mean finding laboratory supply companies that design pipette tip boxes packaging or construction with thinner walls of plastic containers, not only reducing plastic waste, but also saving significant costs in the manufacturing process. In summary, these three strategies can effectively reduce the plastic used manufactured for pipette tip boxes, so that laboratories can have more space to use for other valuable experiments.

We also found that other school initiatives repurposed their pipette tip boxes as a plant pot giving them a second life with educational reason and emotional attachment [17]. Due to the scope of this research and the limitation of the cost and time, we will not discuss the detailed design of the product of the pipette tip box. Instead, we emphasized service models of the pipette tip box recycling program in laboratories provided by MIT EHS.

3.2.2 Survey design—View pipette tip boxes in laboratories in a lens of HCSD

The goal of this case study is to 1) improve the current MIT EHS pipette tip box recycling program and user experience, 2) consider how to scale the initial solutions starting from specific laboratories to the entire campus on multiple types of laboratories and, 3) learn how the MIT initiative to build a safe and sustainable laboratory project can impact our collaborative venders and business strategies.

In our survey, besides covering the sustainable design of pipette tip boxes, including using recycled content, consuming less plastic content, using less packaging, and consuming renewable energy during manufacturing, we specifically focused the questions on two sections: 1) purchasing and 2) recycling, with yes/no question, multiple choices, and open-ended questions so that we can capture the response qualitatively and quantitively. The intention of this survey was to help us understand comprehensively the key touch points across the disposable material flow on campus.

For the first section, purchasing, we were curious about the input of the disposable material flow system. Before discussing the disposal and recycling stage, we need to consider the procurement stage of the system. In the study, MIT VPF has played an important role on procurement. They have started to plan the criteria of "sustainable" purchasing from the institution's perspective: how to build the criteria and who should take the responsibilities in the levels of individual, laboratories, and institution collectively.

Based on the material from MIT VPF and our research, we listed out the questions emphasizing not only people's purchasing behaviors, sustainable product design (e.g., reusable, refillable, and recyclable), but also brands/vendors with sustainable awareness.

For example, do participants know the brand of the pipette tip box or plastic conical tube racks that their laboratory uses? Does the brand provide any pipette tip box or plastic conical tube rack recycling service? How frequently does the laboratory order pipette tip boxes or plastic conical tube racks? Do they or their laboratory choose to buy racked tips or bagged tips? Why do they choose to buy racked tips? Could they use bagged tips instead? Are they aware of sustainable options for pipette tip products? Are they willing to pay more for sustainable pipette tip products? And, if so, how much percentage more (1%, 5%, 10%)?

For the second section, recycling, we want to use the participants' feedback to improve the current MIT EHS pipette tip box recycling program (88% of the survey participants/laboratories have collaborated with MIT EHS box recycling program) and its pain points when people/laboratories do pipette tip box or plastic conical tube rack recycling, for example, time-consuming, lack of clear instructions, the cost of recycling, no incentives/motivation to do recycling, and no one to do the recycling in laboratories.

Some questions we added to the survey: does your laboratory recycle pipette tip boxes or plastic conical tube racks by participating in the EHS managed recycling program or by a direct return to the supplier? If the brand of the pipette tip box or plastic conical tube racks provides recycling services, can you share with us the cost of this service? How many boxes (waste) are being generated per month? We were curious to know whether laboratory participants were interested in expanding their recycling efforts to additional forms of non-contaminated laboratory plastic such as buffer bottles.

In summary, we expected that the survey results hypothetically can help MIT to improve pipette tip box or plastic conical tube rack recycling through setting up a complete recycling program, partnering with right/sustainable vendors/agencies, enhancing people's recycling awareness through education, redesigning the recycling flow across the campus, and making the rental service of pipette tip box or plastic conical tube rack instead of purchasing a one-off experience.

3.2.3 Survey result—Learning points and discussion

In an effort to analyze the survey results we distilled selected interesting insights after the pipette tip box survey analysis covering two sections: purchasing and recycling. In two-weeks, we launched the pipette tip box survey and documented the result from 31 participants ranging from graduate students (18%), MIT EHS representatives (18%), lab managers (36%), and scientists (27%). Since we considered people's attention span within a short amount of time, the survey was made so participants could fill it out within 10 to 15 minutes (Table 2).

Table 2. The demography of survey participants (n=31)

Background	Gender
• Graduate Student (18%) • MIT EHS Representative (18%) • Lab Manager (36%) • Lab Scientist (27%)	• Male (31%) • Female (62%) • Prefer not to say (8%)

- **The information of pipette tip box**

67% of participants knew the brand of the pipette tip box or plastic conical tube racks, whereas 24% did not know and 10% were not sure about their pipette tip box brands. The brands that participants can remember were: VWR, Genesee, USA Scientific, Sorenson, Neptune, Integra, Rainin, and ART. The majority of the brands (80%) didn't provide any pipette tip box or plastic conical tube racks recycling service according to participants' experience. Only 20% of the companies were associated with the product recycling service.

Regarding the frequency of ordering of pipette tip boxes or plastic conical tube racks, 30% of the participants said that they purchased once per month. Only 4% ordered once per week. Some mentioned that the laboratory normally purchased multiple times per month or every other month or even once a quarter. Others said that they had a huge demand for pipette tip boxes, and therefore they order in bulk which is less correlated with the frequency of purchasing.

- **The cost of time and usability from sustainable pipette tip product**

Interestingly, 82% of participants and laboratories choose to buy racked tips and none of them wanted to purchase bagged tips. The rest of 18% did not know how to make a decision. Even though bagged tips were relatively sustainable compared with the racked ones, participants said ease of use, convenience, safety, cleanliness, speed were more critical to them.

One participant said, "Sometimes I buy bagged tips and then put them into racks. However, most people prefer racked tips because they get less easily contaminated. If we buy bagged tips, we would put them into racks ourselves to keep them clean, which can be time-consuming. Also, it is harder to find bagged tips from our suppliers." This also echoes another response: "Bagged tips are too time-consuming to place in racks one by one. I do buy reloads that are already in the wafer saving waste." For most participants, the bagged tip design was not ideal, since they did not have time to stack the tips into racks themselves, and the time cost was not worth it compared with the money they spent.

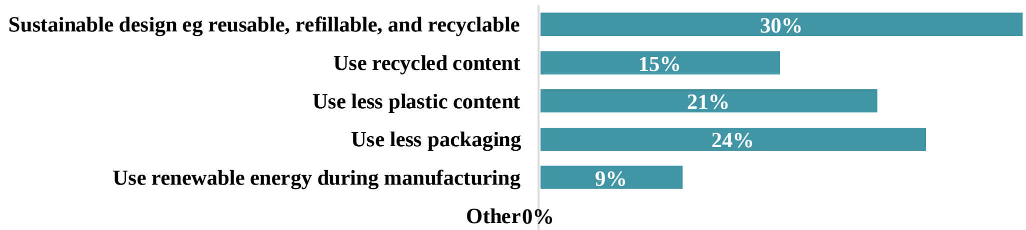

Figure 24. The survey result showed how participants are aware of sustainable options for pipette tip products.

Meanwhile, we were also curious to know if they were aware of sustainable options of pipette tip products exclusive brands and types of tips that we discussed (Figure 24) and how willing they were to put them on their shopping list (Figure 25); 50% of the participants said yes, because it can diminish resources used and improve environmental stewardship, reduce waste to save energy, and it is a "green" action for them. One participant identified the potential problem that "I do think that it can be a small effort for a good cause. However, it would be helpful to have a guide of sustainable pipette tips suppliers and catalog numbers for example. Usually, the issue is the seal or release from the pipettor."

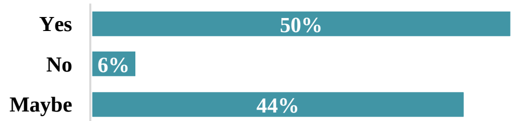

Figure 25. The survey result showed how participants are willing to use sustainable pipette tip products.

Since 44% of the participants replied "maybe," which was close to half of the percentage, we wanted to discuss their intention. Three quotes were clearly captured their reasons:

- *"Sustainable pipette tip product needs to be sustainable within reason. However, convenience and ease of use is far more important."*
- *"We would need to ensure that functionally sustainable pipette tip product works as well as what we use."*
- *"The sustainable pipette tip option has to be compatible with our automation equipment. We are happy to aim to be sustainable as long as it's amenable to our needs."*

In short, people considered sustainable options based on the quality and usability of the product. At least, it needs to be functional to fit the laboratory current pipette system with appropriate pricing.

- **The relationship between the value and volume**

We also discussed the percentage range of pricing that participants or laboratories were willing to pay for sustainable pipette tip products. In Figure 26, we can tell that 5% more significantly stood out among other options.

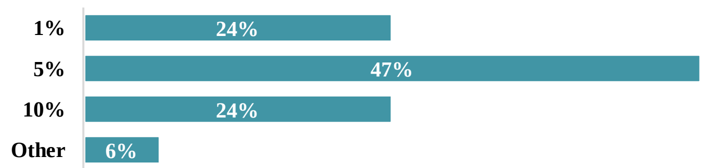

Figure 26. The survey result showed how much percentage more that participants are willing to pay more for sustainable pipette tip products.

A total of 70% of the participants thought the brand of the pipette tip box or plastic conical tube racks provides recycling services should be free, whereas the rest (30%) were unsure how much they should charge for this recycling services, which has a correlation with the volume of the wasted boxes generated from laboratory per month: 60% of laboratories generated boxes under 25 units per month and between 76 units to 100 units accounted for 20%. But this also depends on the types of laboratories and experiments (Figure 27).

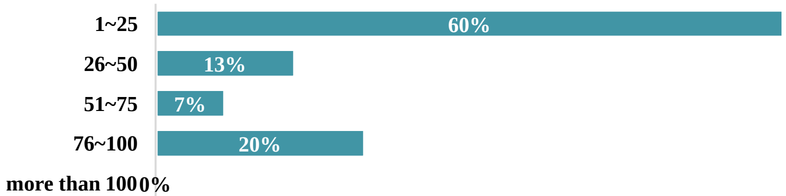

Figure 27. The survey result showed how many boxes (waste) are generated from laboratories per month.

- **The challenges for individual and institutional**

A total of 60% of the participants felt good when they/laboratory did pipette tip box or plastic conical tube rack recycling; 10% felt they were lacking clear instructions or no one actually did the recycling in laboratories; 5% considered the cost of recycling and there was no incentives/motivation to do recycling (Figure 28). But, if we viewed the pain points through the lens of the institute, how would the participants/laboratories help MIT to improve pipette tip box or plastic conical tube rack recycling or how could MIT help the participants/laboratories to do this (Figure 29).

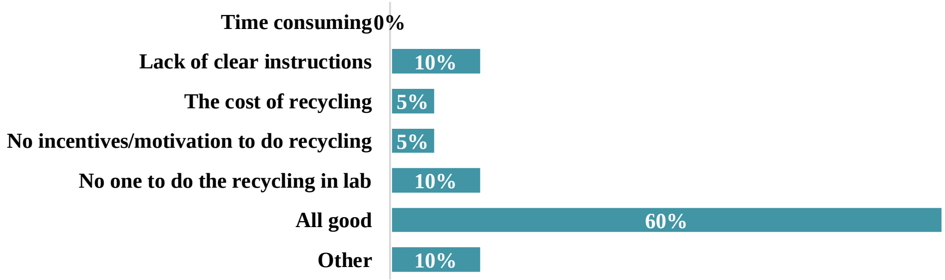

Figure 28. The survey result showed what were the current pain points when participants/laboratories did pipette tip box or plastic conical tube rack recycling.

Figure 29 reveals that besides the current MIT EHS recycling program, 42% of the participants pointed out that MIT should set up a complete recycling program from procurement to disposal and consider people's behavioral change, policy from the government, technology implication, and culture cultivation. Besides the pipette tip box recycling program, 92% of the participants showed their laboratories were interested in expanding their recycling efforts to additional forms of non-contaminated lab plastic such as buffer bottles.

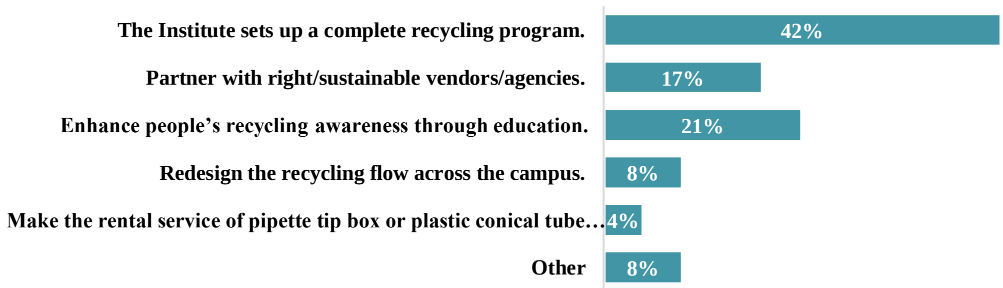

Figure 29. The survey result showed how participants/laboratories would help MIT to improve pipette tip box or plastic conical tube rack recycling.

4. Summary and further study

4.1 Inventory management

"Reuse material, know your inventory, and mindful purchasing are easy concepts, but hard to do," said an expert from MIT VPF. Over-purchasing is a common behavior caused by a lack of material tracking [19]. In our pipette tip box case study, even though 60% of laboratories generated boxes (waste) under 25 units per month, which the waste was relatively little and easy to track, they were still unsure of the number of exact orderings (Figure 27).

According to the field research, interviews and survey results, most people naturally have a mindset to purchasing more is better than less material during their experiment. In conclusion, we observed that improving the laboratory inventory system is a critical step to enable PIs to make smarter material purchases, which also helps laboratory members sort in an organized way before sending them to recycling or disposal [20].

4.2 Human behavior

In our interviews, people said selecting sustainable products is important, but when they make decisions about laboratory material procurement, people naturally consider an item's value per cost first before they think of sustainable impact. Take pipette tip box as an example, 44% of the survey participants replied "maybe" they are willing to use sustainable pipette tip products (Figure 25). It clearly indicated that close to half of the survey participants considered sustainable options in terms of the quality and usability of the product, and the functionality and the compatibility to fit their laboratory current pipettes system with appropriate pricing.

In response to the problem at the institute level, MIT VPF has created a Green Purchasing contract by coining specific terms to make sure vendors not only provide sustainable products with competitive prices but also minimize the carbon footprint of laboratory materials. However, we should carefully take human behavior into consideration when planning sustainable initiatives.

4.3. Safe and sustainable laboratory model

Researching disposable laboratory material flow is the tip of the iceberg of building safe, sustainable laboratories. We need to examine this complex and systemic problem in a comprehensive way to build an ideal model of safe, sustainable laboratories on campus for the future. How do we scale learning from the study? When we consider four phases of material flow analysis, how do we evaluate each phase on the institutional level and individual level?

For further study, we aim to research areas of sustainability practice in laboratories and makerspaces from the perspective of individuals and institutes, identify key touchpoints of disposable material waste with the product and service model, and consider the connection between sustainability actions and people's behavior.

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