Characterizing the Materials Footprint of a University Campus: Data, Methods, Recommendations

by

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Abstract

Universities are major consumers and disposers of many materials, but their specific flows are not well characterized. Both energy and material consumption drive a university's environmental impact. Many universities collect data about their energy consumption (from fuel usage or utility bills) and assess some resulting environmental impacts. However, very little effort has been focused on understanding purchasing, materials handling, and the resulting environmental impacts. To date, there have been few material flow analyses of universities; most analyses concern cities or countries. This paper describes a method for conducting a material flow analysis (MFA) of a university, and it offers the strategies used to obtain first-order characterization and quantification of the flows of the Massachusetts Institute of Technology (MIT).

This case study demonstrates that an MFA of a university requires the use of a portfolio of diverse methods that deliver different outcomes, which then must be pieced together. Inflows and stocks are characterized using financial data, and waste flows are quantified by mass data. Flows are characterized using a combination of product/commodity descriptors and materials.

Material purchases are characterized by product category, temporal variation, purchasing unit/entity, and level of decentralization. The top five purchase categories (by spend) in descending order are: (1) laboratory supplies; (2) hardware purchases/maintenance; (3) laboratory equipment; (4) chemicals, reagents & gases; (5) office furniture. The study also reports the largest stocks of durable goods by quantity and dollar value, as well as the average residence time, or lifetime, of different products. The results also catalogue the quantity and disposal/recycling destinations of different waste streams, including municipal solid waste, single-stream recycling, hazardous waste, medical waste, and radioactive waste.

To estimate the embodied GHG emissions from purchases, spend data was used with an economic input-output life cycle assessment (EIO-LCA). The product categories with the largest embodied emissions were found to be laboratory supplies, chemicals/gases, office furniture, and electronics. The total embodied greenhouse gas emissions of material goods purchased in FY2016 was found to be roughly 78,800 metric tons of CO_2-eq. This is significant compared to Scope 1 and 2 emissions. Emissions from waste management were estimated using waste

generation figures and EPA's WARM model; the results indicate that the greenhouse gas impact from waste is much smaller than that from procurement.

This study also reports the findings from sixteen in-person interviews conducted with MIT community members that make purchases. Among other findings, the interviews revealed that purchasers currently have a high level of individual agency and freedom. Purchasers also reported that they would like easily accessible information and guidelines for how to purchase sustainably, as well as formalized incentives for buying more sustainably and conserving materials.

Currently, the purchasing process is carried out independently of any consideration of the materials' end of life (a linear system, rather than having circularity for sustainability). University entities are autonomous in their purchasing, with some using different systems, which makes complicates the tracking material consumption. This work provides several recommendations for making MFAs easier to perform at the university-level and for reducing the materials and carbon footprint of a research universities. Some key recommendations include: centralizing data collection and storage on procurement and waste; requiring more detailed product-level data from vendors; and creating web-based interdepartmental sharing programs for material goods.

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Table of Contents

Summary of Tables

Summary of Figures

Chapter 1: Introduction

Chapter 1 Abstract

This chapter introduces the thesis and provides context for the research. The motivation for this research is explained and the relevant background literature is reviewed. Characterizing and quantifying material flows and the related environmental impacts of the consumption and disposal of those materials is important for identifying opportunities for impact reduction efforts. Prior to this study, no systematic analysis had been conducted to determine the profile of materials consumed by a technical university. With the knowledge gaps in mind, the research questions and objectives of this dissertation project are articulated. This research aims to establish a method for conducting a material flow analysis of a university or similar organization and to apply this method to the case of MIT.

Topic and Context

According to the World Resources Institute (WRI), global consumption of natural resources in 2050 is expected to be three times the level it was in the year 2000 (World Resources Institute, 2017). Excessive material consumption, especially in wealthier countries, is problematic for sustainable management of scarce resources, management of waste, human health, and climate change. Typically, the life cycle of material goods includes raw materials extraction, transportation, manufacturing, distribution, use, and disposal/recovery. This life cycle is often linear, meaning that after a product is used, it is thrown away. Studying material consumption must be done at the systems level, given the multi stage processes involved, and given that there is such a high level of complexity in time, space, materials, and energy. Specifically, this thesis uses a systems-thinking lens to examine material consumption at the local level of a university campus.

The United Nations officially resolved to work toward seventeen Sustainable Development goals in 2015 as part of their 2030 Agenda for Sustainable Development (United Nations, 2015). Two of these Sustainable Development goals include "*Ensure sustainable consumption and production"* (SDG Goal #12) and "*Take urgent action to combat climate change and its impacts*" (SDG Goal #13). These two goals both relate to the environmental impact of material goods production, consumption, and disposal. Greenhouse gas emissions that contribute to climate change come from directly consuming energy and from consuming materials. Material goods have embodied carbon emissions, which is the carbon dioxide emitted during the processes of mining, manufacturing, distributing, and shipping a material good. Furthermore, the recycling or disposal of products at end-of-life also contributes greenhouse gas emissions, for instance via fuel for transportation or processing of waste.

The UN Sustainability Development goal of "sustainable consumption and production" covers a broad range of industrial and economic activities, including mining, manufacturing, recycling, refurbishing, and disposal. One key method of increasing the sustainability of material consumption and production is to extend the lifecycle of products – this may involve repair and maintenance, component replacement, or identifying secondhand markets/users for unwanted goods. Another method for increasing sustainability of consumption is to increase the circularity of the material flows. Currently, much of the US and the world has adopted a linear approach of material consumption, where individuals and institutions purchase, use, and dispose of the material goods without any cyclical activity. Shifting away from a throw-away culture and toward a circular economy would improve material efficiency. In a circular economy, there would be a much stronger emphasis on returning, renewing, reusing, as well as reducing material purchases. In fact, reducing material consumption as an individual or organization is the most impactful method for reducing the greenhouse gas impact of materials management.

Given the global and imminent nature of climate change, more and more cities and institutions are looking to take matters into their own hands by reducing emissions locally. Not only would it be unwise to wait for international climate agreements, but urban areas are responsible for roughly 75% of the global CO_2 emissions, and therefore have tremendous potential for reducing global emissions (UNEP-DTIE, 2012). In the process of reducing emissions, it is important for cities to first quantify their baseline emissions via carbon accounting. Yet, most cities, companies, and universities only report emissions from Scope 1 and Scope 2, which include direct greenhouse gas emissions (GHGE) from production of energy, combustion, or chemical processes, as well as GHGE from imports of electricity/heat/steam (WRI, 2001). Rarely do GHGE reports include Scope 3 emissions, which are all other indirect GHG emissions (including embedded carbon in materials and emissions from waste management). This is because accounting for materials-related emissions is challenging and requires a substantial amount of detailed data collection; specifically, accounting for materials requires carrying out urban metabolism studies and material flow analyses. However, there is increasing recognition that Scope 3 emissions, especially from businesses and industry are important for addressing climate change.

In order to make and measure improvements in material consumption and/or production, one must first know the baseline of the quantity and types of materials currently consumed by the system of interest. For instance, a city government striving to make improvements in this area would need to know its baseline of annually manufactured goods, procured goods, and disposed material. Quantifying these materials typically requires performing a material flow analysis (MFA). Material flow analysis is the “systematic assessment of the flows and stocks of materials within a system defined in space and time” (Brunner and Rechberger, 2004). It is a valuable tool that can be used to assess the economic impacts and embodied emissions in material consumption. However, a review of the literature reveals that MFAs are usually conducted at the national- or city-level; there are few, if any, urban metabolism studies that have studied *sub-city* units (such as urban districts, living communities, or university campuses).

It should also be noted that interactions with materials at any stage of the product’s life cycle can have human health impacts. For instance, off-gassing from flame retardants embedded in products can be harmful during the use of a product, and incineration as a form of waste management can create poisonous dioxins. Consequently, MFAs can also be helpful for measuring human health impacts, such as toxicity. However, in order for an MFA to be useful for assessing toxicity of materials, it must contain a highly comprehensive accounting of chemicals and materials, which requires knowing a detailed bill of materials. It also requires knowledge of how each type of product is used and disposed of. This type of data was not available for this project, and therefore, this study does not assess human health impacts of materials consumed.

As described by Kennedy et al. (2011), *urban metabolism* involves systems-level quantification of the inputs, outputs and storage of energy, water, nutrients, materials and wastes for an urban region. As part of this process, it is usually necessary to conduct a material flow analysis, in which flows and stocks of materials are quantified using a combination of systems thinking and mass balance. By quantifying resource consumption of non-renewable resources and other materials, this type of work provides data that is necessary (but not sufficient) for urban greenhouse gas accounting; life-cycle emissions factors (such as X kg CO_2-eq per kg of material consumed) are also needed for GHGE accounting.

Universities are major consumers and disposers of a wide variety of materials, but their specific flows are not well characterized. A university's environmental impact comes from both energy consumption and material consumption; universities know their energy consumption relatively well, but to quantify the environmental impact of purchasing and materials handling, material flows must be quantified. To date, few or no material flow analyses of universities have been conducted.

Literature Review

Material flow analysis of complex systems involve keeping track of a large diversity of materials and products. This means a large quantity of data on purchasing, stored goods, and disposed materials must be collected and accessed. Furthermore, conducting an MFA requires using a systematic naming convention, in which materials are identified and grouped consistently.

Material and Product Types

Conducting a material flow analysis requires determining the scope of materials included and then grouping materials into categories. Allesch & Brunner (2015) reviewed 83 studies that focused on Material Flow Analysis for waste management and identified the importance of including both an analysis of the level of products as well as of materials. Taking both the products and the materials into account allows for profound decision making on improving resource and waste management.

Existing material taxonomies (or nomenclature systems) were reviewed to provide context on material categorization. These taxonomies were analyzed for their level of specificity, the mix of material types and product types, and adherence to a standard form.

One of the standard frameworks for categorizing material flows by type at the national level (and often also used at the city level) is the classification of materials outlined in the Economy-wide Material Flow Accounts (EW-MFA) handbook (Eurostat, 2018). This handbook, put together by Eurostat – a statistical office of the European Union – contains the list of materials in its Annex A. It contains eight broad classifications:

1. MF.1 Biomass
2. MF.2 Metal ores
3. MF.3 Non-metallic minerals
4. MF.4 Fossil energy materials/carriers
5. MF.5 Other products
6. MF.6 Waste for final treatment and disposal
7. MF.7 Domestic processed output
8. MF.8 Balancing items

These classes have multiple subclasses of materials, creating a hierarchical taxonomy in which, for instance, MF.1 is Biomass, MF.1.1 is Crops, and MF.1.1.5 is Nuts (Eurostat, 2016)**.** In the new, pared down EW-MFA agreed upon Nov 17, 2016, there are about 130 categories of materials. The older version from 2001 is more extensive, has several hundreds of categories, and drills down to a higher specificity (e.g., Treenuts → Almonds) (Eurostat, 2001). The Eurostat EW-MFA taxonomy is tailored for tracking international physical imports and exports, reporting mining and manufacturing, and producing balancing MFAs. According to Annex III of the Regulation, the EW-MFA is used to "compile different economy-wide material flow indicators for national economies." The breadth of materials covered in EW-MFA is wide, and includes solids, liquids, and gases.

One notable element of EW-MFA is that it contains all classifications in terms of materials, and includes no products, even for characterizing imports and exports; as stated in the Economy-wide Material Flow Accounts Handbook 2018 Edition, "In EW-MFA, traded products are not classified by product classifications, but are assigned to material classes, groups and sub-groups according to the main material the product is composed of" (Eurostat, 2018). To account for the differences in physical imports/exports that go beyond material type, EW-MFA has another layer of classifications that can be used to indicate the "stage" of manufacturing: raw products, semi-finished products, and finished products.

The material taxonomy presented by Ashby's textbook was also reviewed (Ashby, 2009). Ashby's taxonomy has five broad categories:

1. Metals and alloys
2. Polymers and elastomers
3. Ceramic and glasses
4. Hybrids – composites, foams, wood, paper
5. Man-made and natural fibers

There are 61 subcategories across the five categories above, such as copper alloys, polyethylene, soda-lime glass, and cotton. In contrast to Eurostat, Ashby's taxonomy comes from a materials science background and the field of materials selection for specific design and manufacturing performance goals. Ashby's taxonomy is much narrower and oriented for technical materials (solids only); foods, along with many other categories of materials, are not included.

MFA at the National Level

Material flow analysis was originally developed as a tool to be applied at the national level. The method was first defined in The Weight of Nations (Matthews, Amann, & Bringezu, 2000). The Weight of Nations was the product of a collaboration between the World Resources Institute and researchers in Europe and Japan. The goal of the report was to document the materials that flow through national economies and create sets of national physical accounts of materials, as well as develop indicators of materials flows to complicate economic indicators.

MFA is mostly and substantially applied at the national level. As a result, the EURO Stat convention for MFAs are standards were designed for national-level, economy-wide material flow analyses. Typically, when MFA is used to characterize national-level flows, trade data is used. Trade data conveniently provides information on the quantity and value of material goods that enter a country as imports and leave the country as exports. Such national-level MFAs typically focus on mass balance and provide coarse greenhouse gas emission estimates.

MFA at the City and Sub-city Level

Numerous urban metabolism case studies have been conducted for cities around the world, such as Hong Kong, Cape Town, Vienna, Singapore, and Lisbon (Kennedy et al, 2011). One especially interesting study conducted by Rosado et al. (2016) analyzed three cities in Sweden and found that the type and quantity of materials consumed highly depends on the ratio between services and production GDP and the number of large construction projects. The authors used those findings to develop three distinct city consumption profiles: (1) consumer-service, (2) industrial, and (3) transitioning.

An emerging interest in the field of urban metabolism has been the nature of consumption at the sub-city district level (Codoban & Kennedy, 2008). Opportunities that arise include the ease of decision-making and actions at a local level that hold promise for shifting to a more sustainable state. A review of the literature reveals there are few, if any, urban metabolism studies that have studied *sub-city* units (such as urban districts, living communities, or university campuses).

University-Level MFA

Interestingly, universities have the potential to be a unit of analysis conducive to useful knowledge-creation and decision-making similar to that found in the broader urban metabolism literature. Universities have well-defined geographic and political boundaries and tend to keep relatively good institutional-level records of purchase and waste data, which can facilitate materials accounting. Universities, as distinct entities, are largely consumers of resources, with little if any extraction on site. Universities contain a large variety of activities and "industries" that involve consumption of a diversity of material goods; contained within the campus are offices, classrooms, laboratories, a medical center, restaurants, various types of housing, and more. Universities also store resources at a variety of time scales (from days to decades). Universities remove wastes from their spatial extent and disperse those materials far and wide.

In their publically viewable reports, most university and corporate campuses only report the quantity of waste generated, namely reporting the mass going to landfill, recycling, composting, or hazardous processing. I have only found three case studies of universities that have attempted to do partial material flow analyses of their campuses.

The University of British Columbia did in-depth studies of the quantity and composition of waste generated at the university for the purpose of identifying ways to reduce solid waste generation in higher education (Smyth, Fredeen, & Booth, 2010). Smyth et al. found that the campus generated between 1.2-2.2 metric tons of municipal solid waste per week; they also called attention to three material types that provide large opportunities for increased recycling and reduction: (1) paper + paper products, (2) disposable drink containers, and (3) compostable organics.

The University of Michigan also has studied its waste composition in detail – they have quantified the percentage of compostable material in the waste stream of many different campus building types - administrative, classroom, research, residence hall, and student union (Graham Sustainability Institute and the UM Office of Campus Sustainability, 2011). The University of Michigan also made a first attempt at conducting a campus-wide MFA; they quantified the university's expenditure in 10 different purchase categories, such as laboratory supplies, food and beverage, medical expenses, and plant operation and maintenance. They used these expenditure values with economic-input output LCA to estimate environmental impacts in terms of human health (Disability-Adjusted Life Year), kg CO_2-eq and MJ of resources. One noticeable weakness of the work (or difference from my study) is that it did not distinguish between goods and services, which most likely resulted in an overestimation of the materials footprint. As an example, their analysis included travel spend, tax preparation and banking.

One research project applied a systems approach to understanding material flows on a university campus, using the case study of Furman University, a small liberal arts university in South Carolina (Dripps, Gay, & Purvis, 2017). Dripps et al. applied a campus metabolism approach to map inflows, transformations, and material outflows of four resource categories: water, energy, food, and materials. However, the project description available focused on methodology, and did not report results.

Only one prior research project sought to quantify the masses of materials purchased by a university. Tessa Bouzidi of Wageningen University (WUR) wrote her master's thesis on the material consumption of WUR, a Dutch university with a strong agriculture focus. In the thesis, Bouzidi created a "product flow analysis for the university, with the focus of helping the campus transition towards a circular economy (Bouzidi, 2019). Bouzidi's research aimed to identify the 2017 product flows for Wageningen University in terms of mass, costs, and environmental pressure (CO_2-eq and MJ). She utilized purchase records from an online system called ProQme, as well as waste data collected from waste contractors. Because the purchase records did not contain mass values for products, Bouzidi obtained most product weights manually, weighing the products that occurred most in each product subcategory (a total of 138 subcategories). The largest product categories (by mass) were found to be labware, plants, animals/feed, and vehicles. The largest waste streams were found to be mixed trash, paper waste, hazardous waste, and swill waste.

A publication from 2000 reported the greenhouse gas emissions associated with universities, viewed as an industry sector. Rosenblum et al. (2000) used Carnegie Mellon's EIO-LCA tool to analyze four service industries, one of which was "colleges and universities." This paper highlighted certain findings that already existed in EIO-LCA data. The paper reports that the global warming potential of spending one million dollars in the "industry" of colleges and universities is equivalent to 300 metric tons CO_2-eq; and, the total emission output from the sector of colleges and universities in the US is 13 million metric tons CO_2-eq. According to Rosenblum et al., "Colleges and universities are a relatively small sector with small direct impacts, except for emissions presumably associated with laboratory work." The authors also identified the largest supply chain sectors enters colleges and universities for environmental outputs; based on toxic releases, the largest sectors are: primary nonferrous metals, industrial inorganic and organic chemicals, paper and paperboard mills, pulp mills, and miscellaneous plastic products.

Larsen et al. (2013) analyzed the carbon footprint of the Norwegian University of Technology and Science (NTNU). Larsen at al. applied an Environmental Extended Input-Output model to calculate the carbon footprint of NTNU using financial spend data. They found that 30% of the NTNU's carbon footprint comes from non-building materials: 11% comes from "consumables" and 19% comes from equipment, such as lab equipment, machinery, computers, etc. The authors normalized the carbon footprint per student and found it to be 4.6 tons CO_2-eq per student, on average; however, the carbon footprint of a student in social science was 0.58 tons CO_2-eq, versus 10.8 tons CO_2-eq for a student in medicine. Larsen et al. were able to calculate these values by department due to the standardized structure of financial accounting used by the university. When the carbon footprint was normalized by dollars spent, the carbon intensities were fairly similar across different departments.

Although it is rare for universities to report Scope 3 emissions, the University of Cambridge has assessed Scope 3 emissions for fiscal year 2013. Woodhouse and Couling (2014) published a report that estimates Scope 3 emissions of University of Cambridge, which includes emissions from waste collection and management and procurement of goods and services. Their analysis estimated total Scope 3 emissions to be 170,000 tons CO_2-eq. Of this, waste accounted for 5,179 tons CO_2-eq and Procurement accounted for 125,943 tons CO_2-eq (35,018 tons CO_2-eq for Construction, and 90,026 tons CO_2-eq of "Other"). When compared with Scope 1 and Scope 2 emissions, Cambridge found that 36% of total university emissions come from procurement of non-construction materials and services. This proportion is similar to the findings of Larsen et al. It should be noted that this figure does not separate out the impact of material goods from procured services. One weakness of the report is that it does not provide any information on how the authors calculated the emissions figures.

A summary of the literature reviewed above, which address MFA and/or Scope 3 analysis of university campuses is provided in Table 1.

Table 1: Summary of reviewed literature addressing material flow analysis and/or Scope 3 analysis of university campuses***.***

Reference	Year	University	Research Scope	Importance Or Relevant Findings
Smyth, Fredeen, & Booth	2010	University of British Columbia (Canada)	In-depth studies of quantity and composition of waste generated at the university	Found that the campus generated between 1.2-2.2 MT of MSW per week. Found that three streams provide large opportunities for increased recycling and reduction: (1) paper + paper products, (2) disposable drink containers, and (3) compostable organics.
Graham Sustain-ability Institute & Office of Campus Sustai-nability	2011	University of Michigan (USA)	Studied waste composition in detail. Quantified the % of compostable material in waste stream of diff. campus building types: administrative, classroom, research, residence hall, + student union.	Made first attempt at conducting a campus-wide MFA; quantified the university's expenditure in 10 diff. purchase categories, such as lab supplies, food and beverage, medical expenses, and plant operation and maintenance Used these expenditure values with EIO-LCA to estimate environmental impacts in terms of human health (Disability-Adjusted Life Year), kg CO_2-eq and MJ of resources. Study did not distinguish between goods and services, which most likely resulted in an overestimation of the materials footprint.
Dripps, Gay, & Purvis	2017	Furman University (USA)	Applied a systems approach to understand material flows on campus.	Applied a campus metabolism approach to map inflows, transformations, and material outflows of four resource categories: water, energy, food, and materials. The project description available only contained methods, and did not report results.
Bouzidi	2019	Wageningen University (The Netherlands)	Created product flow analysis for the university. Aimed to identify the 2017 product flows for the university in terms of mass, costs, and environmental pressure (CO_2-eq and MJ).	Utilized purchase records from an online system called ProQme, as well as waste data collected from waste contractors. Manually weighed the products that occurred most in each product subcategory (a total of 138 subcategories). The largest product categories (by mass) were found to be labware, plants, animals/feed, and vehicles. The largest waste streams were found to be mixed trash, paper waste, hazardous waste, and swill waste.

Rosenblum, Horvath, & Hendrickson	2000	Carnegie Mellon (USA)	Used Carnegie Mellon's EIO-LCA tool to analyze four service industries, one of which was "colleges and universities."	Reported GWP of spending $1 million in the "industry" of colleges and universities is equivalent to 300 MT CO_2-eq. Found that colleges/universities are a relatively small sector with small direct impacts, except for emissions from laboratory work. Identified the largest supply chain sectors entering colleges/universities for environmental output. Based on toxic releases, the largest sectors are: primary nonferrous metals, industrial inorganic and organic chemicals, paper and paperboard mills, pulp mills, and misc. plastic products.
Larsen, Pettersen, Solli, & Hertwich	2013	Norwegian University of Technology and Science, NTNU (Norway)	Analyzed carbon footprint of the university. Larsen at al. applied an Environmental Extended Input-Output model to calculate the carbon footprint of NTNU using financial spend data.	Found that 30% of the NTNU's carbon footprint comes from non-building materials: 11% comes from "consumables" and 19% comes from equipment, such as lab equipment, machinery, computers, etc. Normalized the carbon footprint per student and found it to be 4.6 MT CO_2-eq per student, on average; 0.58 MT CO_2-eq for a social science student, versus 10.8 MT CO_2-eq for a student in medicine. When the carbon footprint was normalized by dollars spent, the carbon intensities were similar across different departments.
Woodhouse & Couling	2014	University of Cambridge (UK)	Assessed Scope 3 emissions for FY 2013, including emissions from waste collection + management and procurement of goods + services	Estimated total Scope 3 emissions to be 170,000 MT CO_2-eq. Of this, waste accounted for 5,179 MT CO_2-eq and Procurement accounted for 125,943 MT CO_2-eq (35,018 MT CO_2-eq for Construction, and 90,026 MT CO_2-eq of "Other"). When compared with Scope 1 and Scope 2 emissions, 36% of total university emissions come from procurement of non-construction materials and services.

Abbreviations for Table 1:
EIO-LCA = Economic Input-Output Life Cycle Assessment
FY = Fiscal Year
GWP = Global Warming Potential
MJ = Mega Joules
MSW = Municipal Solid Waste
MT = Metric Tons

An analysis of the literature reveals that there are four major knowledge gaps.

(1) All previous comprehensive urban metabolism studies use cases of cities. It remains to be seen if urban metabolism modeling can be applied effectively to a university context.
(2) Most MFAs utilize economic and trade data to estimate flows.

(3) Most universities have little knowledge of the "big picture" of their material consumption profile and there is no established methods for gaining this knowledge. Only with this knowledge can universities characterizes and measure Scope 3 materials-related emissions.
(4) There is no standard material/product taxonomy for characterizing material flows into and out of universities.

Previous Research on MIT

Prior to this project, Prof. John Fernandez and Dr. Julie Newman worked with a small group of MIT students on first developing the idea of an MFA for a university campus: Trygve Wastvedt, Rene Miller, and Rena Yang initiated the project in Spring 2014, and Chaewon Ahn and Jeff Treviño continued the project in June-July 2014. The origins of those projects began in an Industrial Ecology course (MIT course ESD.123) taught by Elsa Olivetti. These initial projects laid down a framework of looking at material flows of different velocities, and first initiated the conversation with the Office of Procurement. Wastvedt et al. and Ahn et al.'s framework separated consumption of materials into "Nondurable," "Durable," and "Semi-permanent" materials. Ahn et al. further separated flows into the four categories based on consumption "velocities:"

V0: Material flows are consumed continuously and remain in the system for a short period of time (water, electricity, natural gas)

V1: Material flows are consumed discretely per day and remain in the system for around 1 year or less (paper, food, office supplies)

V2: Material flows are consumed discretely each 1 - 4 years and remain in the system for 3-10 years (equipment)

V3: Material flows are consumed discretely whenever a building is built and remains for over 10 years (construction materials)

The student work by Wastvedt et al. and Ahn et al. demonstrated four lessons that are useful to this dissertation project. First, it provided proof of concept that a material flow analysis of a university campus is possible, in the sense that the data needed to do an MFA exists in various forms and many places. Second, their work showed that MIT's purchasing did not diminish during the summer, but rather there was a fairly constant level of purchasing through the summer. This may also be true for other research universities that maintain strong activity throughout the summer months; perhaps this is different for liberal arts universities, which may have a greater flux in population over the summer. The third lesson from previous students' work was that purchasing at MIT is complicated – it occurs in so many different parts of the university that it is difficult to understand how it works. This complexity of the system requires a PhD project to understand it. Lastly, since MIT has fairly good control over purchasing, a potential decision to alter purchasing and purchasing behavior is theoretically possible.

Research Questions and Objectives:

The following are the principal research questions driving the research of this dissertation:

> **Q1:** How does one carry out a material flow analysis of an urban university campus?
>
> **Q2:** What are the major material flows into and out of a university campus?
>
> **Q3:** What opportunities exist for increasing efficiency of material consumption and lessening the university's environmental impact from purchasing and disposal of material goods?

In order to answer these questions, the author designed an in-depth case study of MIT's materials consumption. As stated above, MIT serves as a valuable case study for many reasons. First, it is a university that consumes and disposes of a diversity of materials (chemicals, lab equipment, electronics, paper, food, etc.). In addition, MIT has its own power plant, medical clinic, and nuclear research reactor, which distinguish it from other smaller campuses. MIT is also a well-recognized institution with a large budget, and therefore is likely a large consumer of material goods.

Furthermore, MIT believes such a study is important; MIT's Office of Sustainability has invested money and resources into this research and will likely make use of the research findings. MIT's administration may also find the outcomes of this study useful for targeting emissions reductions. Given that MIT has committed to reducing its GHG emissions by 32% by 2030, the university will need to make substantial changes in energy and/or material consumption. MIT began upgrading its Central Utilities Plant in 2017, and is in the process of replacing its old turbine with two new gas-powered ones (MIT, 2019). Consequently, it can be expected that MIT will continue to use natural gas for at least the next 15 years (MIT, 2017). Therefore, MIT has even greater reason to identify opportunities to reduce GHGE via a reduction in its materials footprint.

To direct the case study of MIT, the following research objectives were established:

> **O1:** Characterize the materials flow profile of the campus, revealing consumption patterns for various material groups
>
> **O2:** Quantify the material inflows, stocks, and outflows in terms of dollar value or mass
>
> **O3:** Identify the university processes/activities that have the largest material cost
>
> **O4:** Characterize the organizational structure (including the degree of centralization) of materials purchasing and disposal decisions on campus

O5: Recommend institutional opportunities to increase materials sustainability via institutional policy, organizational changes, or new programs

Overview of the Structure

This thesis contains seven chapters, including this one. At the beginning of each chapter, there is a short abstract, or summary of the chapter's content. Chapter 2 describes the methods for conducting an MFA at a technical university. Chapter 3 is also a methodologically-focused chapter, specifically focusing on the methods associated with data processing purchase records for an MFA. Chapter 4 provides the results of the MFA. Chapter 5 contains the methods for and results of the greenhouse gas estimate of inflows and outflows. Chapter 6 discusses the organizational and behavioral factors that influence purchasing and purchasers at MIT through analysis of interviews conducted by the author. Lastly, Chapter 7 provides a discussion of results, recommendations, and conclusions.

Chapter 2: Methods for conducting an MFA at a technical university

Chapter 2 Abstract

Chapter 2 documents the many-faceted processes involved in conducting an MFA of a university campus, using MIT as a case study. This chapter establishes a method for doing a first-order characterization/quantification of the material flows. The objective was to track all major material inflows to, stocks within, and outflows from the university's campus, excluding construction materials, fuel, and water. In this chapter, the boundary and scope of the study are established, and the methods for gathering and analyzing various data sources are described. The chosen year of study was MIT's Fiscal Year 2016 (FY16). Procurement purchase records were used to understand inflows, minor property/assets data were used to characterize stocks, and waste handlers' data in combination with primary data (waste audits) were used to estimate outflows. The results of the waste audits are also reported in this chapter. Material flows were characterized using a combination of product and material categories, and a new, university-specific material taxonomy was created. This case study demonstrates that an MFA of a university requires the use of a portfolio of diverse methods, which deliver different outcomes that then must be pieced together.

Introduction to Methods

This chapter documents the many-faceted processes involved in conducting an MFA of a university campus. The authors used MIT as a case/test study. MIT is a technical, research university located in Cambridge, Massachusetts, USA. The methodological lessons learned are likely applicable to other university campuses, and perhaps beyond to other institutions or sub-city units. This case study demonstrates that an MFA of a university requires the use of a variety of methods that provide different results, which then must be integrated to construct the system analysis. In order for this to be done successfully for an MFA, data needs to be gathered in a systematic and economical way. A number of challenges were encountered during this undertaking. Some of these challenges were resolved, and others are further analyzed in the Discussion chapter. Some challenges can only be resolved with more data.

Boundary and Scope

Multiple factors might be used to determine the scope and boundaries in a university-level MFA: (1) geographic boundaries, (2) activity sectors and missions (research, education, and operations), (3) fiscal responsibility for materials, (4) governance over material decision-making, and (5) types of materials.

For this analysis, the physical bounds of the system are relatively clear, given that the campus has defined geographic boundaries. In this case, the area of study was limited to MIT's Cambridge main campus, which is primarily contiguous and encompasses 166 acres. This main campus includes 190 buildings that comprise roughly 13 million square feet. Other MIT-owned or associated properties at separate locations (Lincoln Laboratories and the Haystack Observatory) were excluded. On-campus dormitories and housing communities (fraternities and sororities) were included, but off-campus housing was excluded.

To track what materials were purchased and handled by the Institute, the geographic boundary was used in conjunction with the administrative, organizational structure of MIT. The campus serves a population of roughly 22,500 students, faculty, researchers and staff. The Institute has several levels of organization and serves educational, research, administrative, and operational purposes. Administratively, the university has five schools, the sum of which contain 31 academic departments. There are also over 400 other entities that span research labs, centers, operational units, and administrative organizations. Knowledge of these subdivisions, along with an understanding of their political and monetary control over materials, was used to determine the MFA system boundaries. This helped ensure that all major activities and populations consuming materials were included in the analysis.

The materials and products included in the scope of the MFA are highly diverse, ranging from lab supplies to electronics, to food. However, some major streams, namely tap water and sewer water, fuels, and building materials were excluded. This scope is illustrated by Figure 1. When determining the scope of an MFA for a university campus, there are strong implications surrounding the inclusion of building materials from construction and renovation. Campuses often expand rapidly and frequently renovate, and therefore their materials consumption profile may be dominated by building materials, if such materials are included. The lifetimes of building materials and common consumable goods (food, office supplies, furniture etc.) are so different that separating the two allows for a logical divide in terms of data collection and recommendations for decision making. Lifetimes of buildings are much longer, and the magnitude of masses is much greater than other consumed materials. In order to focus the research on consumable material goods, a choice was made in this study to exclude building materials. Water (for drinking, bathing, heating, etc.) and fuel were also excluded from the scope.

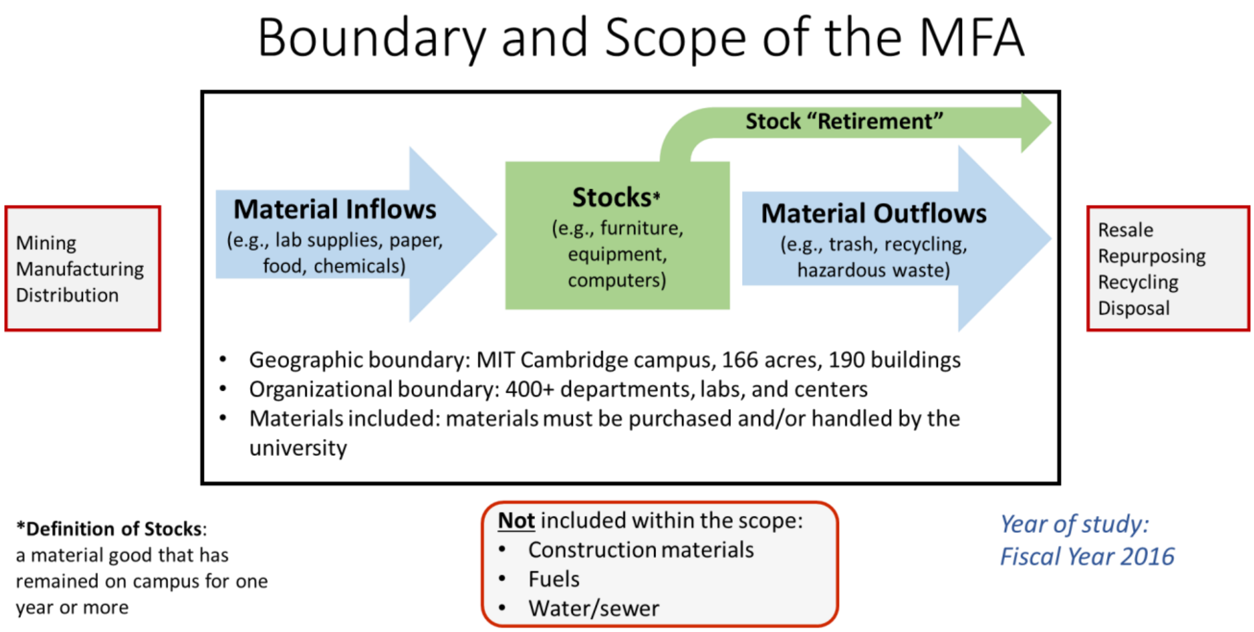


Figure 1: A graphical representation of the boundary and scope of the MFA performed in this study. The contents within the black rectangle are included within the study, and the elements outside of the black rectangle are excluded.

Defining Inflows, Stocks, and Outflows

The objective of this MFA was to track all major material inflows to, stocks within, and outflows from the University's campus, excluding construction materials, fuel and water. Materials were counted as inflows if they were purchased by an MIT organization/entity located on the main campus or a contracted campus vendor (e.g., vendor operating the MIT dining hall). Here, the fiscal responsibility was clearly traceable to MIT whereby the Institute made the purchase directly or indirectly via a larger contract.

Material flows were tracked and quantified at the annual scale (according to the fiscal year). The year of study was chosen to maximize the quantity and quality of data available, while being as current as possible. This MFA is for Fiscal Year 2016, also known as FY16, which covers the dates of July 1, 2015 through June 30, 2016.

A given material's lifetime was used to distinguish flows from stocks. Materials residing on campus for a year or longer were defined as stocks. All rapidly-consumed materials purchased and disposed of within a given fiscal year (e.g., food, disposable cutlery, and printer paper) were considered to be both inflows and outflows for that same year.

Outflows were defined as the materials the university is responsible for removing from the campus as waste, recycling, reuse, or donation. In most cases, the collection of these flows is done by university staff or hired contractors. Any material once classified as an inflow or stock that is removed from campus was treated as an outflow. It should be noted that a small portion of outflow materials qualifies as an originally private purchase that becomes the material responsibility of the university. An example of this is the packaging and food waste from packed lunches, brought to campus by students and staff.

The General Approach

Early on, it became clear that conducting an MFA at MIT was a large undertaking that involved a diversity of data collection strategies, data sources, and methods of analysis. Given that a major question of this study was, "how does one conduct an MFA for a university?" the method used in this project involved experimental components and some trial and error. The general approach taken to perform this MFA is shown in Figure 2. The general approach of data collection for this MFA involved three parallel types of activities:

(1) Defining the boundary and scope
(2) Obtaining and aggregating data from university entities
(3) Collecting primary data to supplement the exisiting data

Subsequently, the disparate data sets were aggregated and used with a set of analytical methods to create an MFA and systems-level analysis of the university. Specifically, this analysis involved the following four tasks:

(1) Process and integrate disparate data sets from multiple sources
(2) Assign materials and products categories from the appropriate taxonomy
(3) Normalize units to enable comparison and summation of material flows
(4) Quantify material inflows, outflows, and stocks to best-possible approximation

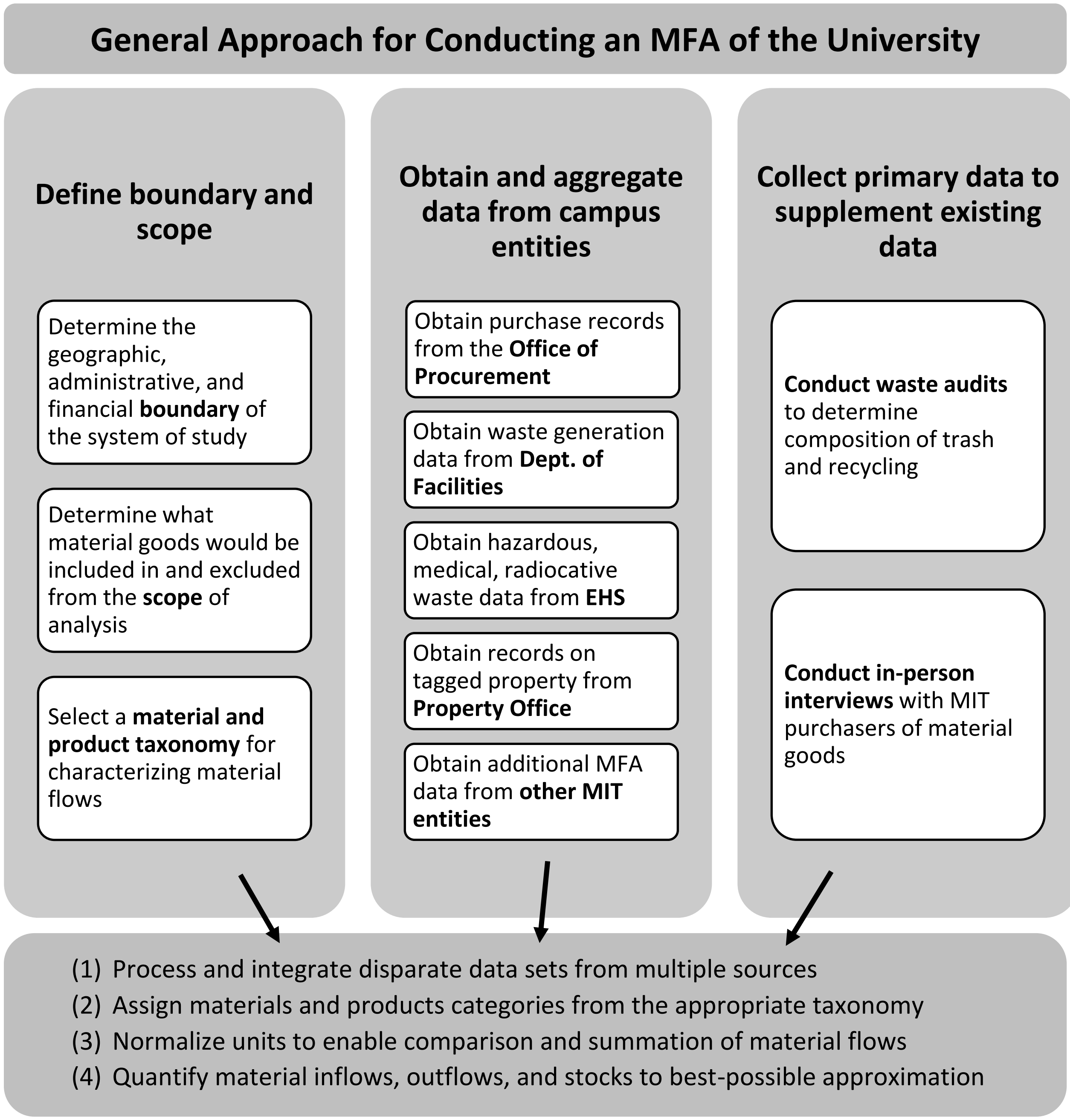


Figure 2: The general approach of data collection for this MFA involved three parallel types of activities: (1) Defining the boundary and scope, (2) Obtaining and aggregating data form university entities, and (3) Collecting primary data to supplement the exisiting data. After that, the disparate data sets were aggregated and used with a set of analytical methods to create an MFA and systems-level analysis of the university.

In practice, conducting many of the above-mentioned activities was challenging. Some of the primary challenges included:

- The system is complex because there are multiple ways to purchase goods for/at MIT
- Unexpectedly high level of effort and delays involved in establishing contact with MIT staff and obtaining data from several different offices and departments
- Messy and incomplete data sets that were difficult to process
- Clear presence of data, but unclear ownership of and policies for sharing that data (i.e., lack of data governance)
- University concern about security and sharing institutional data with a student researcher
- Necessity to establish trust with university operational entities to enable data sharing with the student researcher

In order to overcome these challenges, the author used the following strategies, among others:

1. Form connections with various operational and administrative entities within the university that are involved in the collection and management of institutional data.
2. Develop a working partnership with the Office of Sustainability.
3. Gain publicity within the university about the project. Elicit excitement and exposure to the project to higher-up financial administrators, who eventually would be more willing to approve the sharing of data with the researcher.

More detail about these challenges and specific recommendations for avoiding and/or overcoming them are discussed in Chapter 7.

To overcome the above challenges, one tactic that this author used was to directly work and collaborate with strategically powerful university actors. This helped the author, a student researcher, establish trust and connections with the right people. Specifically, the author gained credibility through a combination of working with the Director of MIT's Environmental Solutions Initiative (ESI), MIT's Office of Sustainability (MITOS), and by establishing relationships with various operational entities. With the Directors of MIT's ESI and MITOS on the doctoral committee, this research truly demonstrated a collaboration between academics, operational departments, and the university's Office of Sustainability. Figure 3 symbolizes this intertwined relationship between these three different actors at the University, all of whom rarely come together for the purposes of applied research. One finding from research is that the establishment of relationships with university administrators and operational staff can be just as important as establishing relationships with academics. Collaboration between these actors is necessary for accomplishing interdisciplinary work within such a complex system of separated research university departments/groups.

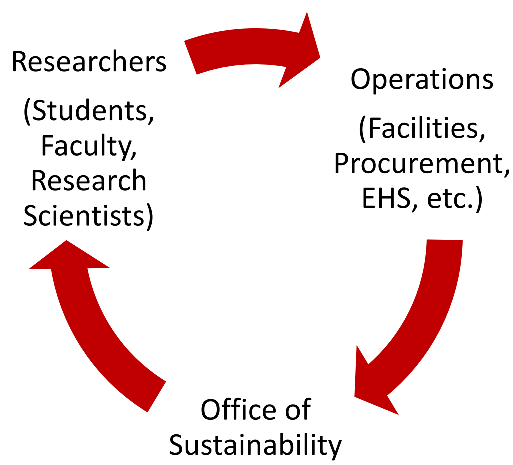


Figure 3: Schematic diagram showing the intertwined relationship between researchers, operations, and MIT's Office of Sustainability.

Gathered Data Sources

Gathering data for this MFA required the acquisition of several disparate data sets, managed by different MIT departments and groups. (2) Obtaining and aggregating data form university entities, and (3) Collecting primary data to supplement the existing data

Table 2: Summary of the data sets collected for the development of a materials flow analysis for the university.

DATA SET	DATA TYPE	DATA SOURCE	CONTENT OF DATA SET
Procurement electronic catalog (ECAT)	Secondary (Inputs)	Office of Procurement, VPF	- 2.6 million records for purchases made between 2006-2017 through the Electronic Catalog - Contains line-item records with product descriptions and price
Interview Data	Primary (Purchasing Behavior / Organization)	Rachel Perlman (author)	- Qualitative data on individual and organizational purchasing behavior - Interviews were with a variety of purchasers (administrators, laboratory managers, facilities staff, etc.)
Property Office Data	Secondary (Stock)	Property Office, VPF	- Contains the purchase date and “deactivation” date, if applicable of MIT property with a value over $3,000
Waste Audit Data	Primary (Outputs)	Rachel Perlman (author) and volunteers	- Contains compositional data (percentage by weight) on trash, recycling, and food waste - Five audits on MIT’s campus. 21 material categories
Municipal Solid Waste Generation Data	Secondary (Outputs)	Office of Recycling and Materials Management, Dept. of Facilities	- Contains mass of waste streams generated by on campus for FY 2009-2016
Waste Cooking Oil Data	Secondary (Outputs)	Newport Biodiesel	- Data available for FY 2013 – FY 2017 - Reports gallons generated by each dining location that collects waste cooking oil for recovery
Hazardous, Medical, and Radioactive Waste	Secondary (Outputs)	Dept. of Environment, Health, and Safety	- Contains mass quantities of waste generated - Contains 137 hazardous waste categories, 3 medical waste categories, 3 radioactive waste categories

Qualitative Data Collection: Interviews

To better understand how purchasing works, in practice, at MIT, the author interviewed a diversity of MIT community members that regularly make purchases of material goods. The intention was to learn about the personal experience of people who make purchases. These human perspectives could enhance understanding of the system, beyond the objective purchase record data. Specifically, subjective interview responses can provide depth and reveal unexpected elements about the purchasing process and purchasing behavior. The author conducted in-person, semi-structured interviews that lasted between 20 minutes and 1 hour. Before conducting the interviews, the author underwent human-subjects research training and obtained approval for the study from MIT's Committee on the Use of Humans as Experimental Subjects (COUHES). The author followed the interview guide provided in the Appendix.

Sixteen MIT community members (n = 16) were interviewed in this project. Each interview involved detailed questions, and the findings provide valuable insight about the cultural context of purchasing at MIT. The detailed methods and results of these interviews can be found in Chapter 6.

Inflows

Centralized vs. Decentralized Sources of Purchase Records

Within the scope of this project, the materials entering a university campus as inflows mainly are purchased goods. With the purpose of cataloging these inflows, the ideal, simple solution is to gather all of this data from one source. For this project, obtaining such data took a significant amount of time (1.5 years to obtain the initial set of data).

Due to the delay in data sharing by Procurement, the author explored two options: (1) gathering data directly from purchasing entities within the university and (2) requesting the centralized records from Procurement. Meeting with MIT's Copy Tech, an on-campus printing facility, provided valuable information on the quantity of paper, ink, and printers consumed on campus. By meeting with MIT's Custodial Services, the author learned that that office's purchased materials (cleaning supplies, toilet paper, etc.) are not purchased through ECAT, but are rather purchased through contracted purchase orders. They willingly shared a year's worth of purchase records, but did so via paper print outs of several long Excel-documents, which proved tedious to process and categorize. MIT's Mail Services appeared to be a logical group to meet with, given that they are the principal gatekeeper for the majority of purchased goods delivered to campus. It was learned that not all packages coming into MIT are delivered via Central Mailing Services; rather, some arrive via direct delivery from the vendor (e.g., office supplies from Staples or some lab equipment). Although Mail Services was able to explain its logistics and estimate the number of trucks full of packages that arrive daily, they did not know the weight of goods carried by the trucks. They also did not know the mass of individual packages. The author did consider the possibility of doing a manual audit of the weight of packages delivered in a given amount of time to determine an estimate of the mass of packaged goods delivered to campus in a year. However, this was not done due to limited time.

The author also requested data directly from some of MIT's largest vendors of material goods. For instance, MIT's dining vendors were approached to request purchase records. They provided data for different time-scales, and categorized their purchases and food differently. Staples was the only vendor that, upon request, provided weights (masses) of the products it had sold to MIT.

Obtaining purchase records directly from MIT entities and vendors proved to be useful, but very time consuming. It also introduced inconsistency: materials and purchases arrive via so many different channels, that the data itself is inconsistent (or contains different attributes). The decentralized strategy of directly approaching university entities had some benefits: it created network connections; it increased the author's understanding the campus as a complex system; and sometimes it also led to the acquisition of new and/or enhanced data. However, more often than not, the data sets were difficult to merge with one another, or were for non-overlapping time frames.

Overview of Procurement Data

Two primary sets of purchase records were obtained from the Office of Procurement. Both covered the year of study, FY16, and one of the data sets covered prior years, as well. The first was the ECAT database, which contained line-item level purchases made through the online catalog. The second was a much larger portfolio of spend that included ECAT, but also included many other spend channels. The scope of these FY16 purchase records is shown below in Figure 4. These two purchase record data sets are qualitatively compared in Table 3. The ECAT data contains a smaller subset of purchase records, but contains more specific attribute information, such as the product description, manufacturer, and number of units. In contrast, the FY16 Total Spend data set covers a much larger subset of purchase records with a lower level of detail – there are no product descriptions, manufacturers, or product quantities. As is true with most purchase records, neither data set provides product weight (mass) or material type.

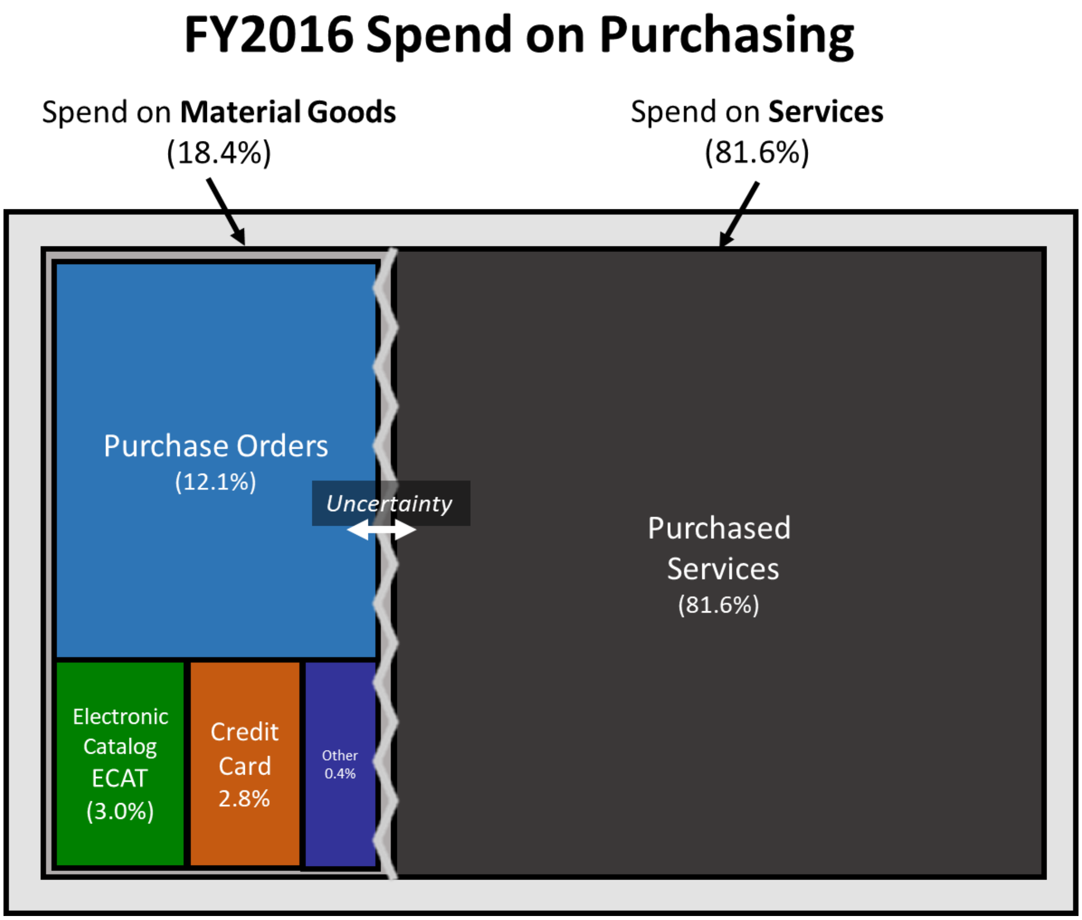


Figure 4: A visual representation of MIT's spend on purchasing. The full rectangle shows the total FY2016 spend, which is divided into material goods (18.4%) and services (81.6%). The division between these two is represented by a wavy line, representing the uncertainty involved in discerning products and services with the limited level of detail available in the data. The focus of this study is on the material goods, which is further broken down into spend methods, such as purchase orders, ECAT, credit card.

Table 3: Qualitative differences between the two primary data sets used to analyze material inflows: ECAT and FY16 Total Spend.

Data Quality Feature	ECAT data set	FY16 Total Spend data set
Completeness: Fields are fully completed, with few empty values	Low	High
Granularity: Level of detail	High	Low
Accuracy: How well the data corresponds to reality	High	High
Orderliness: How consistent the format and structure are	Medium	Medium-high
Supplier	✓	✓
Spend	✓	✓
Product Description	✓	X
Product Category	✓	✓
Product Weight (Mass)	X	X
Material Type	X	X

Dollars spent on purchased material goods and services is shown in Table 4. It should be noted that expenditure on services far outweighs the expenditure on material goods. However, within material goods, the largest dollar amount is spent via Purchase Orders. It also should be noted that these spend values are the raw values that were provided by the Office of Procurement, and are not refined to confirm correct categorization. This refinement of goods vs. services is discussed in Chapter 3.

Table 4: Estimated spend (in dollars) by MIT on material goods and services in Fiscal Year 2016.

Material vs. Service	Spend Channel	Spend (%)
Material Goods	Credit Card	2.8%
	ECAT	3.0%
	Purchase Order	12.2%
	Other Material Purchases	0.4%
Services	Purchased Services	81.6%
	TOTAL	100%

About the Full FY2016 spend records from Procurement

The purchase record data was sourced from the university's analytics system, which loads from data exported from the University's Data Warehouse. The data was limited to Fiscal Year 2016. The Office of Procurement helped the researchers exclude a significant quantity of purchases that were, with high certainty, purchases of non-material goods. For instance, the Office of Procurement did its best to eliminate from the data set the following types of invoices: fees, human resources tuition payments, prize money, royalties, software, contracts, and others.

As shown by Table 5, within the dataset are purchases from three main channels:

(1) Purchases made through the online catalog (ECAT) - 16.5% of the spend
(2) Purchases made through University credit cards - 15% of the spend
(3) Purchases made through invoiced Purchase Orders - 66% of the spend

There are some other small purchase channels that do not fit into these categories, and have been grouped together as the "Other Channels." The total percentage of spend made up by purchases in these Other Channels is 2.4%.

Table 5: All FY16 purchased material goods listed by purchase channel.

Spend Channel	Percentage Of Spend
Credit Card	15.05%
ECAT	16.50%
Other Channels	2.43%
Purchase Order	66.02
Total	100%

Table 6: Description of the main purchasing channels used to buy material goods for MIT.

Purchasing channels with records kept by the central Procurement Office	Description of Spend Channel
Electronic catalog, ECAT (now called Buy2Pay)	Online ordering/invoicing direct to about 60 preferred vendors. University-wide discounts have already been negotiated for purchases via this platform. Fastest option for purchasing goods under $5,000.
Purchase Order Invoice	This is the spend method for contracts, large-quantity purchases, or expensive equipment. Detail on product or service description is entered by the buyer and based on quotes.
Credit Card (P-card)	The preferred method for buying low-dollar orders (less than $3000) from suppliers that are not in the electronic catalog. Used for one-time purchases with new vendors, as well as recurring purchases. The data covers 246,000 transactions. Credit cards are often used for buying from online purchases and caterers.
Lab Supplies	Spend on lab supplies purchased from the on-campus lab supply stockroom. Stockroom is mostly used for quick/urgent lab purchases and small supply purchases.
Non-PO Invoice	Other spend type that includes the materials (serials, books, and publications).
Employee Reimbursement	Reimbursement for goods that were originally purchased with personal cards/cash.

In total, there were 620,882 rows of data, each representing an invoice. This spend totaled $256.4 million, before any additional processing by me to exclude services and items outside of the scope of study. The highest level of detail we were able to see was invoice level data; it should be noted that any given invoice can often have multiple purchase line items, but we were unable to see this level of detail because those are mostly scanned versions of paper invoices.

Attributes of the VPF Purchase data:

The following are the attributes (or fields) of the data that were most relevant to this research:

- **Category** – Spend category, which is derived from the university's analytics tool, using its classification engine for procurement categories.
- **Subcategory** – The "Category" and "Subcategory" fields are connected, with the second having nested subfields of the others. Subcategory has actual subcategories of "Category."
- **Document Type –** Indicates the purchasing channel of a purchase at the University.
- **Spend amount –** Spend in dollars.

Less reliable but still available for reference:

- **GL Description (General Ledger)** – Another potential indicator of spend category. It is entered by the user from a list provided. One problem with the GL Description is that 16M of purchases are categorized as the ultra-broad category of "Goods and Services," which provides zero information on product type. Can be most accurate Purchase Orders (suggested by Procurement).
- **Material Group** – System requirement in which the user selects from a list developed originally by Procurement (SAP functionality)

The field "Subcategory" was determined to have the most accurate descriptor of the type of purchase made, and was used distinguish product/goods purchases from other non-material, or low-material intensity purchases, such as services, fees, and software. There purchases do not always reflect direct material purchases, especially when contracts are involved, but they do provide some information. For instance, for food, contracts with dining vendors have a Subcategory of "Dining and Vending."

The author bucketed the 124 different Subcategories into three groups, to determine whether or not they should be included in the Product Flow. These categories were:

1. Material Goods within the Study Scope
2. Material Goods Outside of the Study Scope
3. Non-materials / Services

Material Goods within the Study Scope included subcategories such as:

- Books
- Chemicals, reagents, and gases
- Drugs and pharmaceuticals
- Laboratory supplies
- Janitorial supplies
- Printers
- Telecommunications equipment

Examples of Material Goods Outside of the Study Scope included:

- HVAC
- Natural Gas
- Plumbing

Examples of Non-materials/ Services were:

- Accounting and auditing
- Airfare
- Dues/fees
- Electricity
- Royalties

A full list of the Subcategories and their corresponding categorization as material goods vs. non-material goods can be found in the Appendix.

During the data collection process, it became apparent that material classification, and specifically translating between product-level and material-level categories, would be a challenge. Purchase and inventory records were at the product level (laptops, centrifuges, gloves), while waste records were listed as a combination of materials (food waste), product categories (batteries), and disposal destinations (mixed trash going to incineration). Some types of waste, such as hazardous waste and techno-waste were characterized with high resolution in large part due to the regulation surrounding those materials. It became apparent that certain streams, especially equipment and electronics made of many kinds of materials, had to be categorized as products since material composition was complicated.

Normalizing flows by unit quantity was also challenging. In product form, material purchases were quantifiable by count, and often by economic value (spend in dollars by MIT). However, mass was an unavailable attribute in such records, and could only be found via product-research (searching by SKU) or estimation. Conversely, most waste streams were measured by mass, as the waste handler or receiving company provided the university with records in terms of mass. By going through invoices associated with campus waste management, we were able to identify a cost per mass for most material streams. Consequently, dollar value or expenditure was the most readily-available unifying unit measure involving the fewest assumptions and data processing.

Stocks

The traditional distinction between flow and stock is that a flow is a variable measuring a quantity per time period, whereas a stock is a variable measuring a quantity at a certain point in time. As defined by this study, stock is comprised of material goods that reside on campus for longer than one year. As compared to inflows and outflows, stocks were much more difficult to quantify.

There was no “smart” way, such as a list of barcodes or formal inventory, to know all of stored material on campus. This was primarily due to the fact that the University does not track the majority of products during their lifetime of storage and use. However, the University’s Property Office does require that all new equipment with a value of $3,000 or more be tagged. The Office also tags computer equipment (desktops, laptops, and servers) valued at $1,000 and above. When an item is tagged, it is given a tag number and cataloged as an item “activation;” each tagged item also has a recorded acquisition value, a book value, storage location, responsible personnel, supplier, manufacturer, and standard name. The standard name is a general product type such as “television,” “pump,” or “freezer.” Some items also have a model number and/or serial number. When an item leaves the campus, protocol calls for the item to be “deactivated.”

Primarily for accounting and tax purposes, the Property Office maintains a record of all activations and deactivations, and keeps a database of all “active” items, meaning all items which have been tagged but have not yet been deactivated. We requested access to and received these records, which had never before been used for academic research or an MFA. The active items represent some portion of the stock, and the number of years between a product's activation and deactivation represents its residence time on the University's campus. Due to the fact that less expensive items are not tagged, the dataset was certainly limited in its scope and could not be used to catalog the full stock of products/materials residing on campus. We are doubtful that the majority of stock as measured *by mass* is captured by this dataset. For instance, small furniture, lab glassware, or books would not be found in the list of active stock. However, we are more confident that the majority of stock as measured *by monetary value* is in fact in the database.

Specifically, the data we had available to use for an analysis of stocks was the following: the records for all items activated starting in FY 2009 through FY 2016 that were still "active." We did not have data on items acquired before 2008. The dataset had over 29,000 records. The total value of the active items at time of acquisition was roughly $339 million. The data included 930 different standard product types, and the items with the highest count were laptop computers, desktop computers, servers, and lasers.

The top 100 most commonly cataloged products constituted 88% of the active items. The author did her best to match these products to materials in our Material Taxonomy and estimate average weight. The author used online research about products, including about specific popular model numbers, to estimate these weights. For instance, the most common laptop model was a 2014 model 13.3 inch Apple Macbook, so we used this model's weight (1.6 kg) as the average weight of a laptop. The most common copier was the Konica Minolta C364E model, so we used that copier's weight (85 kg) as the average weight of a copier.

The authors also had data on all items deactivated during the same time frame of FY2009-2016, which consisted of 47,415 individual deactivations and 1,379 unique product types. This data provided valuable insight on the campus lifetimes of higher value products; using the time difference between activation and deactivation dates for products of the same type, we determined the average lifetime (and variance) for common products such as electronics, freezers, desks, and centrifuges. Knowing these lifetimes can provide an institution with a better understanding of behavior surrounding durable goods and their retention, repair, or discard.

This analysis does raise the question – unanswerable with this data set – of what is the active use lifetime versus passive uses lifetime. Particular areas of improvement might be identified through discovery of underutilization or a need for incentivizing repairs instead of fully replacing equipment. Furthermore, each deactivation included a "disposal type" which was either a general "deactivation" or a more specific indicator of the product's destination beyond the University, such as it being transferred to another owner, gifted, scrapped, or sold. If a system such as this were fully utilized to track the outlets of goods, a university would have a high quality information on its disposal and reuse of high-value products. Ultimately, exploration into this property data set, originally maintained for tax-related accounting, illustrates that at least the high-value "stock" in the University context can be tracked and analyzed for better understanding of longevity and the behavior around storing and discarding those assets.

Outflows

The general method of estimating masses of waste coming out of the campus was to:

(1) Use the university's data where possible to obtain volumes of various waste categories
(2) Supplement by gathering data if possible from individual entities / experts on campus
(3) Conduct empirical waste audits to gain higher resolution data on the composition of large, heterogeneous waste categories

Estimating the overall masses of waste from the campus was more streamlined than it was for inflows of purchased goods. Requests were made from multiple departments to obtain waste data. These departments include the University's Facilities Department, the Department of Environment, Health, and Safety (EHS), the IT Department and Dining.

Facilities provided monthly mass volumes for a number of waste streams, such as trash, single stream recycling, yard waste and certain specialty recycling streams such as batteries and scrap metal. The majority of these masses were originally provided to Facilities by the hauling vendors, since the removal was priced by a per-pound fee. Similarly, the data on hazardous and medical waste provided to us by EHS originally comes from invoices provided by the waste hauler.

In contrast to the MSW, the data on hazardous and medical waste required processing to estimate masses, given that many of the specific hazardous waste streams were measured by the quantity of metal drums or number of liquid gallons. The author obtained hazardous waste, medical waste, and radioactive waste quantities from EHS. The author consulted EHS in order to transform this data, but our mass estimates contain some level of error, due to missing information such as a given waste drum's level of fullness upon disposal. After processing the hazardous waste data to obtain mass quantities, the author aggregated the highly specific streams such as "PCB caulking" or "Consolidated flammable solvents" into more general categories such as "Corrosive" or "Ignitable" materials.

Our total estimate of solid waste (excluding C&D waste) generated in FY 2016 is 5,423 MT, of which 49% is trash and 23% is single stream recycling. Unfortunately, beyond knowing the total mass of single stream recycling and trash (two streams with high material heterogeneity), there was little to no information on the composition of those streams. To better understand the two largest waste streams – mixed trash and single stream recycling – the author used waste audits to determine their composition.

Waste Audits

In 2016 and 2017, the author conducted five waste audits at different buildings (with different functions) around campus to identify the materials contained in trash bins, recycling bins, and in some cases compost bins. These audits involved segregating the waste into 21 categories, which listed below in Table 7. Photos of the waste audit are shown in Figure 5.

The procedure for each waste audit was as follows:

1. Freshly generated (from the previous ~24 hours) waste material was gathered from bins. To do this, advanced planning needed to be done with Facilities, custodial teams, and the building manager to coordinate that the waste was aggregated from various spaces within the building and was not removed before we could sort it.

2. Waste sourced from recycling bins was sorted separately from the waste sourced from trash bins in order to allow characterization of "recycling bin material" and "trash bin material." Additionally, when a compost/food waste bin was present, that waste was also sorted separately to categorize "food bin material."

3. We readied a waste sorting location. This location was usually in a loading dock area or outside, if the weather permitted. We taped down tarps to the floor/ground to contain the mess of the designated bag-opening area and set up tables (also covered in tarps) for the bins and scales. Bins were laid out with laminated signs that had category name/descriptors and some images of the types of contents that belong in the category.

4. I led and coordinated the waste audit to ensure consistency across audits. Participants were provided with safety equipment (gloves, Tyvek coveralls, etc.) and were trained on the sorting methodology. The sorting categories were pre-defined and explained to avoid ambiguity.

5. Participants hand-sorted the waste into the 21 categories (food waste, film plastic, PET bottles, etc.). The participants were volunteer MIT students and staff. The 21 categories are outlined below. During the process, if participants had questions about which category a particular item belonged to, I or the director of the recycling program at the University made the judgement call. I was involved in all of the weighing/data recording, which allowed me to do a quality-control check of the contents in each category.

6. Each of the 21 categories of sorted waste was weighed and those masses were recorded in a data sheet. This was typically done in cycles, while participants took a break from sorting, to prevent the sorting bins from overflowing and becoming unwieldy. The tare function on the scale was used to eliminate the bin weight and only measure the sorted contents.

7. Upon completion of the audit, the sorted material was properly disposed of in recycling, trash bins, and food waste for compost/anaerobic digestion as appropriate.

Materials used in the waste audit:

- Plastic bins/buckets for holding sorted waste
- 5 digital battery-operated scales
- Tyvek coveralls
- Rubber, latex and nitrile gloves
- Laminated signs
- Goggles
- Tarps
- Duct tape for taping tarps and signs
- Foldable tables
- Waste receptacles for disposal of the waste post sorting
- Magnet for helping distinguish between steel (magnetic) and aluminum (usually not magnetic)

Figure 5: Two photos of a waste audit conducted outdoors on MIT's campus.

Table 7: List of material categories used in the waste audits of this study, as well as the corresponding appropriate destination for such material on this particular university's campus.

Material categories used in waste audits (21 categories)	Appropriate destination bin on the University's campus
Food waste	Food collection bins (going to anaerobic digestion)
Yard waste	Food collection bins (going to anaerobic digestion)
High grade copy paper	SS Recycling
Mixed paper	SS Recycling
Boxboard	SS Recycling
Paper cartons (e.g. Tetra Pak)	SS Recycling
Corrugated cardboard	SS Recycling
PET containers (#1)	SS Recycling
HDPE containers (#2)	SS Recycling
Misc. recyclable plastic containers (#3-7)	SS Recycling
Aluminum	SS Recycling
Steel	SS Recycling
Glass containers	SS Recycling
Soiled paper products	Trash
PLA bioplastic	Trash
Film plastic	Film plastic recycling
Multilayer packaging	Trash
Polystyrene foam (i.e., Styrofoam)	Styrofoam recycling
Batteries	Battery recycling
Small electronics	Techno-waste recycling
Other / misc. waste	Trash

Notes on terms: SS Recycling = Single Stream Recycling. PLA bioplastic = Polylactide biodegradable plastic, often made from corn.

Some clarification on sorting rules and answers to frequently asked questions by participants is contained in Table 8.

Table 8: Sorting rules used to segregate materials into waste audit categories**.**

Material categories used in waste audits	Clarification on contents or (non-exhaustive) examples of the contents for each category
Food waste	Uneaten food including bread, meat, dairy. Also, food scraps, bones, tea bags, egg shells
Yard waste	Rare in audits, most yard waste from campus handled by Grounds team. If present: non-food plants/leaves/woody twigs. Wooden chopsticks.
High grade copy paper	White paper, notebook paper, printer paper, white envelopes
Mixed paper	Colored paper, magazines, newspapers, brown paper bags, junk mail, shredded paper
Boxboard	Also known as paperboard. Cereal boxes, cracker boxes, egg cartons, toilet paper rolls, similar material.
Paper cartons (e.g. Tetra Pak)	Juice boxes, milk/cream boxes, coconut water cartons.
Corrugated cardboard	Sturdy cardboard boxes, clean pizza boxes
PET containers (#1)	Most clear, disposable water or soda bottles. Or other recyclable containers with #1 on bottom.
HDPE containers (#2)	Milk jugs, laundry detergent bottles. Often opaque. Will have a #2 on bottom.
Misc. recyclable plastic containers (#3-7)	Yogurt containers, iced coffee cups, plastic strawberry containers, sushi containers
Aluminum	Soda or drink cans, aluminum foil, aluminum trays
Steel	Tuna cans, soup cans, other steel items
Glass containers	Glass bottles and jars. Lids kept on.
Soiled paper products	Paper towels and napkins (if wet, the wet weight was recorded), paper food “boats,” soiled paper food containers, soiled pizza boxes, paper coffee cups, used tissues
Film plastic	Single-use plastic bags, plastic wrap. Usually stretchy and clear. Included the trash bags used by custodians to collect waste.
Multilayer packaging	Chip bags, candy wrappers, bubble-padded envelopes, etc. Multiple materials laminated together - these are usually a flexible polymer film adhered to paper and/or aluminum
Polystyrene foam (i.e., Styrofoam)	Foam containers, foam cups, packing pellets, laboratory packing foam
Batteries	Any type of battery
Small electronics	Chargers, headphones, electronic accessories or cables

PLA bioplastic	PLA utensils, cups, or clamshells. There is frequently a leaf / biodegradable symbol or word on item. Utensils often more yellow in color and more flexible
Other / misc. waste	Traditional/petroleum-based disposable utensils, straws, iced-coffee lids, ketchup packets. Textiles, ceramics, bulk items, or other durable items. Anything that doesn't fit in other categories.

The 21 material categories were chosen for one or more of the following reasons: (1) existing as a segment category in previous audits at other institutions/cities, (2) being common contaminants to recycling or compost, (3) having a distinguishable value to the waste processor (4) being of interest for the purpose of conducting the MFA or environmental analyses. These audits are unique in their level of specificity. Most university audits separate waste into fewer categories, providing much lower resolution information on material composition.

A total of five waste audits were carried out on five different days. The date, source of waste, and total mass of material sampled/sorted is listed in Table 9. Waste was sourced from a variety of locations / buildings / uses of space, in an attempt to obtain a relatively representative sample of the campus, as a whole. As shown in Table 9, audits were done of waste from an undergraduate dormitory (Audit #1), two sets of academic and research spaces (Audits #2 and #3), and two different types of dining areas (Audits #4 and #5).

Due to the limited number of volunteers and amount of labor required to run a successful waste audit, the total number of audits completed was relatively low. With a greater budget, more audits could potentially be carried out using paid labor or waste consulting services. Regardless, any audit will inherently represent a snapshot in time (time of year or day of the week may influence composition) and only a certain region of campus, and thus may not fully represent the composition of waste at the annual scale of an MFA.

Table 9: Description of the five waste audits conducted at MIT.

Audit number (for reference)	1	2	3	4	5
Date conducted	1/30/2017	8/23/2016	6/30/2016	5/18/2017	8/22/2017
Description of source of waste	Undergraduate dormitory of ~300 students	Business school classrooms, Offices with students and staff	Scientific research labs, Offices, Science/engineering/math classrooms. Sourced from 7 buildings	Residential dining cafeteria (all you care to eat), mostly used by undergraduates	A-la-carte (i.e. retail) dining cafeteria mostly used by grad students and staff
Mass sampled from trash bin	188.4 kg (incl. recycling)	68.4 kg	64.6 kg	32.8 kg	52.0 kg
Mass sampled from recycling bin	Included in trash	40.8 kg	182.6 kg	15.4 kg	11.4 kg
Mass sampled from organics bin	N/A	N/A	N/A	87.5 kg	40.1 kg
Presence of extra audit category: segregated Edible vs. Non-edible food waste	no	no	no	yes	yes
Other notes	Recycling and trash were too highly mixed to distinguish. All were in black bags.			Separately sampled waste from the kitchen v. front of house	Separately sampled waste from the kitchen v. front of house v. dishroom

Waste Audit Results

Based on the waste audit and as shown by Table 10, the average composition of MIT's trash contained 29% food waste, 20% soiled paper products (such as paper towels, used coffee cups, and napkins), 6% mixed recyclable plastic containers, 5% mixed paper, and 4% poly-lactic acid bioplastic. The other categories constituted less than 4% of the stream, excluding "other/miscellaneous waste," which comprised 13% of the contents. This composition is visualized in Figure 6. It should be noted that 31% of the trash contents were compostable, 50% were recyclable in single stream recycling, and only 18.5% were truly trash.

Table 10 also shows the average composition of MIT's recycling bins. The recycling contained 22% corrugated cardboard, 20% PET containers, 10% mixed paper, and 7% soiled paper products, with all other categories comprising less than 5% of the total contents. On average, 77.5% of the recycling bin's contents were actually recyclable based on the local recycler's acceptance rules. This means that the contamination rate was 22.3%. The largest contaminating streams were soiled paper products (6.9%), film plastic (4.6%), and food waste (3.9%).

Table 10: Average composition (by weight) of the waste in MIT's single stream recycling bins, based on the campus waste audits. Green = compostable, blue = recyclable in single stream recycling, and red = disposable or recyclable using specialty recycling services.

WASTE CATEGORY	Average Composition of Campus TRASH	Average Composition of Campus RECYCLING
Food waste	29.2%	3.9%
Yard waste	0.3%	0.0%
Soiled paper products	20.2%	6.9%
PLA bioplastic	4.5%	2.5%
High grade copy paper	1.9%	5.1%
Mixed paper	4.6%	9.7%
Boxboard	2.3%	1.9%
Paper cartons (e.g. Tetra PAK)	0.4%	0.0%
Corrugated cardboard	2.3%	22.4%
PET Containers (#1)	2.3%	20.0%
HDPE Containers (#2)	1.4%	5.0%
Misc. recyclable plastic containers (#3-7)	6.0%	5.6%
Aluminum	1.2%	4.4%
Steel	0.5%	0.4%
Glass containers	4.2%	3.0%
Film plastic	2.3%	4.6%
Multilayer packaging	0.5%	0.3%
Polystyrene foam (i.e., Styrofoam)	0.0%	3.3%
Batteries	0.5%	0.0%
Small electronics	2.2%	0.8%
Other / miscellaneous waste	13.0%	0.0%

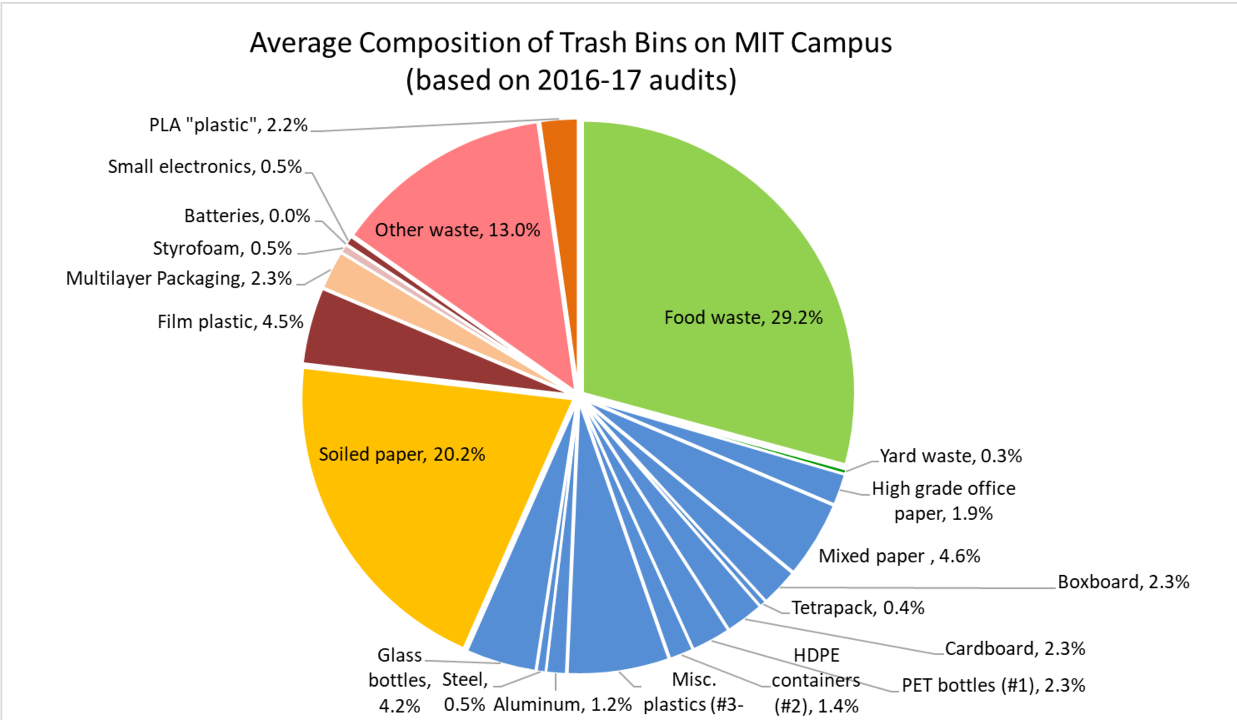


Figure 6: Average composition of MIT's trash bin contents, based on the campus waste audits.

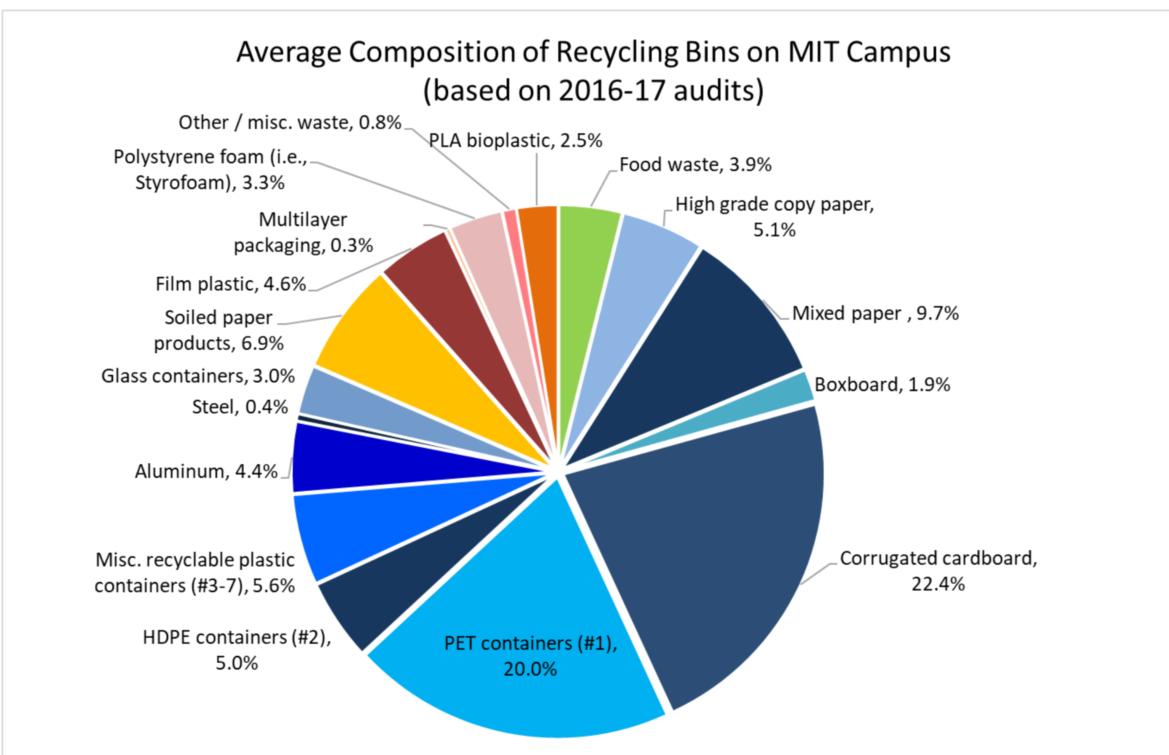


Figure 7: Average composition of MIT's recycling bin contents, based on the campus waste audits.

Incorporation of Waste Audit Data into the MFA

The author used the waste audit data to estimate average campus compositions (by percentage) of trash and recycling. She then used these averages and the total masses of trash and recycling to estimate mass flows of each of those 21 material categories, for instance allowing us to estimate the tons of cardboard recycling leaving the campus. This added significant detail to the waste flows of the MFA, which we rarely see in other characterizations of university waste streams. In addition to enriching knowledge about material flows, such detail improved our ability to estimate the greenhouse gas emissions associated with hauling and management of campus-generated waste flows.

The last step of characterizing the outflows was to catalog the processing method / destination of each stream. This was done by consulting the University entities that provided data, and when needed, contacting the waste processor to better understand their facility and processes. The majority of the MIT's trash is incinerated, while its single stream recycling is segregated at a local Material Recovery Facility for domestic and overseas recycling. The recovered food waste (sometimes referred to as compostable waste) is slurried and anaerobically digested at a regional facility that co-digests food and waste water solids. Most of the hazardous and medical waste generated from labs is sent to hazardous waste incinerators. Radioactive waste is packaged into containers for long-term land storage at Superfund sites.

It should be noted that these outflows are almost exclusively limited to streams generally categorized as waste streams. We know that some products leaving the university enter secondary markets. Due to a lack of data, we were unable to quantify the mass of materials leaving the University as donations or items for future reuse outside the institute, although we believe this flow to be non-negligible. These goods include collected items from book drives, student move-in and move-out days, and other reuse channels. Some higher-value items with purchase values over $5,000 are tracked by the University's property office using the classification of "Sales, transfers, donations." Unfortunately, these products are tracked by quantity and general product type such as "centrifuge," making mass estimates challenging, not to mention that using this data would severely underestimate the total quantity of sales, transfers, and donations, given the price-value floor of products tracked.

Creation of a Material Taxonomy

Existing material taxonomies (or nomenclature systems) were reviewed to provide context on material categorization. These taxonomies were analyzed for their level of specificity, the mix of material types and product types, and adherence to a standard form.

One of the standard frameworks for categorizing material flows by type at the national level (and often also used at the city level) is the classification of materials outlined in the Economy-wide Material Flow Accounts (EW-MFA) handbook (Eurostat, 2018). This handbook, put together by Eurostat – a statistical office of the European Union – contains the list of materials in its Annex A. It contains eight broad classifications:

1. MF.1 Biomass
2. MF.2 Metal ores
3. MF.3 Non-metallic minerals
4. MF.4 Fossil energy materials/carriers
5. MF.5 Other products
6. MF.6 Waste for final treatment and disposal
7. MF.7 Domestic processed output
8. MF.8 Balancing items

These classes have multiple subclasses of materials, creating a hierarchical taxonomy in which, for instance, MF.1 is Biomass, MF.1.1 is Crops, and MF.1.1.5 is Nuts (Eurostat, 2016). In the new, pared down EW-MFA agreed on Nov 17, 2016, there are about 130 categories of materials. The older version from 2001 is more extensive, has several hundreds of categories, and drills down to a higher specificity (e.g., Treenuts → Almonds) (Eurostat, 2001). The Eurostat EW-MFA taxonomy is tailored for tracking international physical imports and exports, reporting mining and manufacturing, and producing balancing MFAs. According to Annex III of the Regulation, the EW-MFA is used to "compile different economy-wide material flow indicators for national economies." The breadth of materials covered in EW-MFA is wide, and includes solids, liquids, and gases.

One notable element of EW-MFA is that it contains all classifications in terms of materials, and includes no products, even for characterizing imports and exports; as stated in the Economy-wide Material Flow Accounts Handbook 2018 Edition, "In EW-MFA, traded products are not classified by product classifications, but are assigned to material classes, groups and sub-groups according to the main material the product is composed of" (Eurostat, 2018). To account for the differences in physical imports/exports that go beyond material type, EW-MFA has another layer of classifications that can be used to indicate the "stage" of manufacturing: raw products, semi-finished products, and finished products.

The material taxonomy presented by Ashby's textbook was also reviewed (Ashby, 2009). Ashby's taxonomy has five broad categories:

1. Metals and alloys
2. Polymers and elastomers
3. Ceramic and glasses
4. Hybrids – composites, foams, wood, paper
5. Man-made and natural fibers

There are 61 subcategories across the five categories above, such as copper alloys, polyethylene, soda-lime glass, and cotton. In contrast to Eurostat, Ashby's taxonomy comes from a materials science background and the field of materials selection for specific design and manufacturing performance goals. Ashby's taxonomy is much narrower and oriented for technical materials (solids only); foods, along with many other categories of materials, are not included.

After searching and learning about previously existing material taxonomies, the author determined that no existing material taxonomy was especially well suited to the context of a University's material consumption profile. A new taxonomy was created. This new taxonomy incorporates relevant elements of previously existing taxonomies, modifies certain groupings, and expands the specificity (subclasses or branches) of material groups important in a university setting. This taxonomy is referred to as the University-Specific Material Taxonomy, and was designed with the following in mind:

(1) Find a balance between breadth, specificity, and a manageable size to analyze
(2) Be applicable for characterizing waste streams coming from a technical university
(3) Where possible, create a taxonomy transfer to classifying waste streams (not just inputs)

The University-Specific Material Taxonomy contains a similar structure to EW-MFA. However, there are some major changes. The balancing items (e.g., oxygen for respiration) were excluded because this project did not mass-balance the inputs/outputs of a university system, due to practical limitations. Some of Ashby's material categories are incorporated, Ashby's taxonomy helped generate ideas around some technical materials that the university would be consuming. The most important difference between the two taxonomies is that this new taxonomy preserves some products as products, rather than materials; this is true for products such as batteries, computer components, light bulbs, printer ink.

Some unique elements to the University-Specific Material Taxonomy are the following:

- It is a hybrid of material and product designations, with a preference for materials when possible.
- There is an extensive set of chemical materials that
- Electronics and some other products with complex combinations of materials are categorized as products.

The structure and general categories of the University-Specific Material Taxonomy are the following:

1. **Biomass:** 46 subcategories (e.g., nuts, candy, wood, and paper)
2. **Metals:** 15 subcategories (e.g., iron, steel, and aluminum)
3. **Non-Metallic Inorganics:** 17 subcategories (e.g., salts, glass, and water)
4. **Fossil energy materials:** 7 subcategories (e.g., hard coal and natural gas)
5. **Plastics:** 27 subcategories (e.g., PET, PLA, Nitrile, and Neoprene)
6. **Chemicals and Compressed Gas:** 99 subcategories (e.g., nitric acid, isopropyl, and nitrogen gas)
7. **Electronics:** 51 subcategories (e.g., lead-acid batteries, printers, laptops, and medical equipment)
8. **Other Products:** 13 subcategories (e.g., multilayer packaging, adhesives, printer ink, wax)

To avoid key missing items, the taxonomy was shared with others in related fields to see if there were noticeable gaps. Purchase records and the list of UNSPSCs found in purchase records were also reviewed carefully [see Chapter 3] to see if the likely material match for that product was present in the taxonomy.

Chapter 3: Methods for Processing Electronic Catalog (ECAT) Purchase Record Data for use in the MFA

Chapter 3 Abstract

This chapter explains the methods used to process purchase record data for the purpose of estimating material flows entering the university. Two purchase record data sets were analyzed in this study. The first data set contained line-item records purchases made through MIT's electronic catalog (ECAT). The second data set contained all purchase records made during the 2016 fiscal year, including online orders, purchase orders, credit card purchases, but contained less detailed information about each purchase. This chapter focuses on the first data set, ECAT, and describes the data sets' characteristics, data processing needs, and utility for this study. The chapter also explains the methods used to clean the data, identify data fields valuable for MFA, distinguish products from services, and create a complete product categorization. Given limited data, the researchers used natural language processing of irregular product descriptions in an attempt to identify the material type of purchases. This chapter highlights the power, as well as limitations, that purchase records have for understanding a university's material consumptions in terms of mass and material type.

Description of the Electronic Catalog Purchase Record Data

MIT's Electronic Catalog (ECAT) is a web-based ordering platform that was widely used by the MIT community to make purchases. The purchasing platform was used by all departments and groups, and was maintained and supported by MIT's Office of Procurement. The ECAT data set contained line-item records purchases made through MIT's online purchasing system. The ECAT data had over 24 attribute fields, such as Extended Price, Fiscal Year, and Manufacturer, for each purchase record. It should be noted that some fields contained a large portion of Null values. The list of the data fields and their descriptions can be found in Table 11.

As can be seen from Table 11, the ECAT purchase records had relatively specific product-level data. When an MIT community member made an online purchase from the university's preferred vendors, it was recorded in ECAT, and therefore ECAT is a central record of purchases from different departments. The most unique and useful element of this dataset is that it contains line-item level product information on the purchases. In contrast, other channels of purchasing (not through ECAT) generated less specific records, for instance, lacking product descriptions.

Table 11: A summary of the data fields and contents of the ECAT data set.

Data Attribute	Description	Example(s) of Contents and Format
Amount per UOM or UOM	Sometimes indicates unit of measure (pack); sometimes indicates quantity per pack (5 per pack)	EA, PK, ML, QT, CS, DZ, BX, 100/PK, 1/EA, 5/PK, 0.5/ML
Category Level 1	General category of product, based on UNSPSC Segment (least specific of the four)	Spectroscopy; Manufacturing Components and Supplies; Office Equipment and Accessories and Supplies
Category Level 2	Category of product based on UNSPSC Family	Moldings; Well drilling and operation equipment; Compounds and mixtures
Category Level 3	Category of product based on UNSPSC Class	Lenses, Rod, Screws
Category Level 4	Category of product based on UNSPSC Commodity (most specific).	Allen screw, Laser mirrors, Stainless steel rods, DNA Polymerase Enzymes
Creation Date	Date order was placed through the order system	1/8/2009
DLC	Organizational category of entity, referring to Department, Lab, Center	Department, Lab, Center
Extended Price	Price of purchase	72.74, 1850.00
Federal ID Number	Federal tax identification number of supplier	REDACTED
Fiscal Year	Fiscal year according to the July 1 – June 30 calendar	2015
Manufacturer	About one fourth of the records (558,267 of 2,073,798) have Null for the Manufacturer field	Aldrich, Dell, Null
Manufacturer Catalog Number	Not consistently filled out, but when populated appropriately this is the catalog number for that particular item in the supplier's online catalog	218235, N5260, Null
PC Level2 Category	The general organizational entity that made the purchase.	Engineering, Science, VP Research, Graduate Education, Office of Provost
PC Level 3 Category	Specific organization entity that made the purchase.	Chemistry, Mechanical Engineering, Media Laboratory
Product Description	Long string description of the purchased product. Formatting and level of detail varies greatly across records	1/2" x 1" Stainless Steel Optical Post, 8-32 Stud, 1/4"-20 Tapped Hole
SAP PO Number	Purchase Order number used for tracking by Office of Procurement	4501663350
Ship to Address Internal Name	Building to which package is initially received on campus	Stata; E19_Recvng; Bldg_56
Ship to Contact 2	Final building to which package is delivered	Blg76, BlgE19
SKU Catalog Number	Stock Keeping Unit provided by supplier	04518320, 78226-01
Supplier Duns Number	Data Universal Numbering System used to identify the business of the supplier	REDACTED
Supplier Name	Supplier (sometimes a distributor) name	REDACTED
Quantity	Number of units purchased in a given record	1, 2
Unit Price	Price per unit	137.00, 45.30
UNSPSC	The United Nations Standard Products and Services Code: taxonomy of products and services for use in eCommerce. It is a four-level hierarchy coded as an eight-digit number.	44120000, 44121903

Overview of Processing Methods

After analyzing the individual data fields contained within ECAT, the author determined that the data would need extensive processing if it were going to be useful for understanding the university's material inflows. Figure 8 outlines the general process used to process and analyze the ECAT purchase records. Of the six steps, the first four (in blue) were fully completed, and the last two (in gray) were not completed. The data comes from a system that captures financial transactions. The fields captured that are relevant for the MFA are not necessarily relevant for processing the financial transaction. This has direct impact on the quality of the MFA-relevant data captured, which needed to be heavily processed to be made useful for the analysis. The first step was to clean the data. For instance, we needed to eliminate duplicate records and eliminate unused (empty) fields that used computer memory but provided no information. Second, we selected the study period (FY2016) so that we could translate findings into the context of an MFA. Third, we identified the data fields that were valuable for performing an MFA. Some of the most important data fields were: product description, quantity, purchase date, price, UNSPSC, supplier, and manufacturer. Next, we built a classifier for product categorization (per the UNSPSC framework) using natural language processing. This process is described in detail later in this chapter. The last two steps – assigning materials from the material taxonomy and assigning masses to – were unable to be completed because of data limitations.

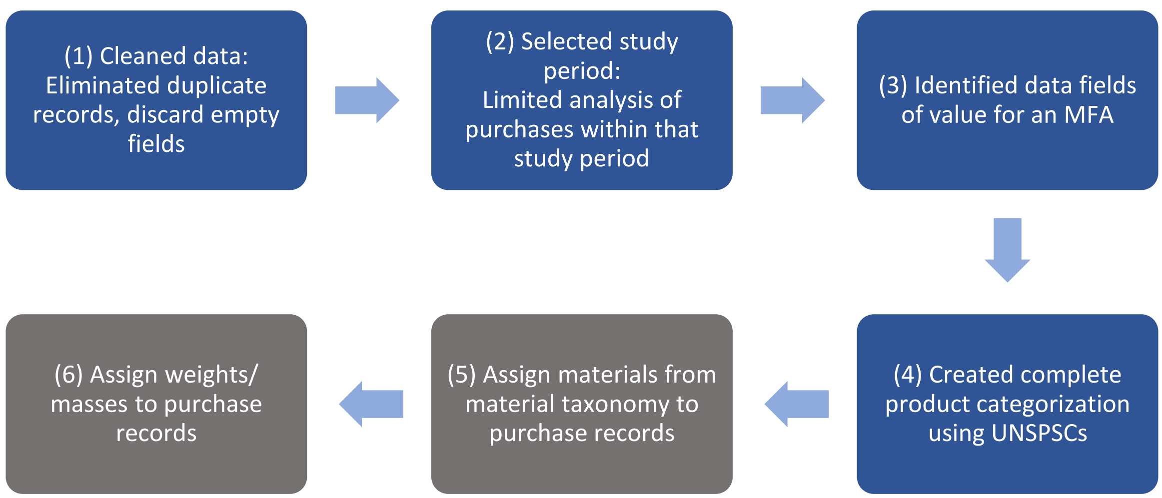


Figure 8: A flow diagram of the general process used in this study to process and analyze the ECAT purchase records. The blue rectangles are completed actions and the grey rectangles are actions that were attempted but that were not fully completed due to data limitations.

Distinguishing Products from Services

We were aware that some purchase records within the data set were purchased services, which did not constitute material goods. We wanted to estimate the fraction of records that were "products" vs. "services," and differentiate those records, so that service purchases were eliminated from the MFA. As a first pass to get a sense of the quantity of services, we randomly sampled 500 records from the 269,375 total record for FY2016, and read through those product descriptions. We did not find a single service.

In total, 2,202 records contained a Null value for the Segment attribute, and none of these appear to be services. Within this null group, the product descriptions all clearly referred to products, such as “screws,” “needle holders,” or “headsets.” As shown Table 12, 7,060 records in all years (2008-2017) contained a (non-Null) Segment titles including the word “service.” One of these Segments was the category “Management and Business Professionals and Administrative Services and Environmental Services.” However, this label was found to sometimes be misleading, given most purchases with this Segment tag were in fact products like adhesives, batteries, cleaners, and tape. This finding indicated that it was unreliable to use Segment title to determine whether a purchase record was a service. Consequently, we pursued other ways of identifying purchases of services.

Table 12: Instances of ECAT Segment categories containing the word “service.”

Segment.Title
Building and Facility Construction and Maintenance Services
Editorial and Design and Graphic and Fine Art Services
Education and Training Services
Engineering and Research and Technology Based Services
Environmental Services
Farming and Fishing and Forestry and Wildlife Contracting Services
Financial and Insurance Services
Healthcare Services
Industrial Cleaning Services
Industrial Production and Manufacturing Services
Management and Business Professionals and Administrative Services
Mining and oil and gas services
Public Utilities and Public Sector Related Services
Service Industry Machinery and Equipment and Supplies
Transportation and Storage and Mail Services
Grand Total

Our next strategy was to look for service-related words in the records’ Product Descriptions. We identified the following key words as words that might indicate the presence of a service: “service,” “services,” “deliver,” “delivery,” “license,” “-year,” “warranty,” “applecare,” “software.” If the product description contained one of more of these key words, the purchase was tagged as a service. We created a new field, called “Is_Service” that featured a Boolean variable of either True or False. If this variable was True, it was considered a service. If it was False, it was considered a product. Fewer than 800 records contained one or more of these service-identifying key words in the product description. These records constituted about $200,000, which, by expenditure, was only 0.07% of the total purchases in ECAT. Any purchase tagged with a True for Is_Service was excluded from analysis.

Improving the Specificity of Product Categorization

ECAT's Product Categorization Prior to Processing

One of the most useful attributes in ECAT was the UNSPSC, or the United Nations Standard Products and Service Code. The UNSPSC is an "open, global, muti-sector standard for efficient, accurate classification of products and services"(UN Development Program, 2019). UNSPSCs each have eight digits, representing four hierarchical classifications, consisting of two-digits:

- Segment: The logical aggregation of families for analytical purposes
- Family: A commonly recognized group of inter-related commodity categories
- Class: A group of commodities sharing a common use or function
- Commodity: A group of substitutable products or services

Each two-digit suffix is associated with a descriptive category name. An example of the structure is shown in Table 13.

Table 13: The hierarchal structure of the UNSPSC system.

Hierarchy	Code	Category Number	Description
Segment	**44**000000	44	Office Equipment and Accessories and Supplies
Family	44**12**0000	12	Office Supplies
Class	4412**16**00	16	Desk Supplies
Commodity	441216**17**	17	Staplers

This hierarchy of classifications is visualized in Figure 9. The top level categories are examples of Segments, and the bottom-most categories are examples of Commodities.

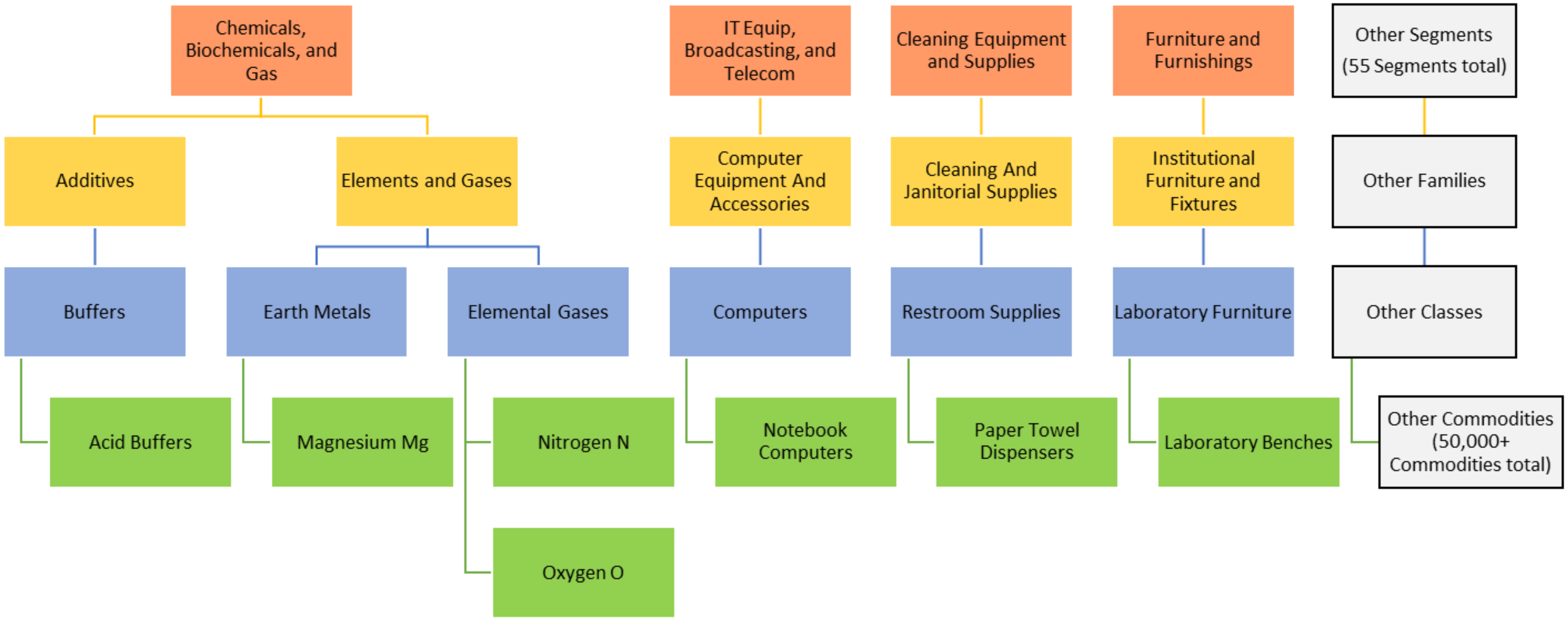


Figure 9: A hierarchical visualization of the United Nations Standard Products and Service Code (UNSPSC) classification system, showing a small sample of categories.

Within ECAT, there were 269,375 purchase records for FY2016. All but 297 rows (0.11% of the data) had an associated code that at a minimum specified the Segment. The level of specificity of the UNSPSCs varied in the original data set, as shown in Figure 10 and Figure 11. The number of null values increases further down the hierarchy of specificity.

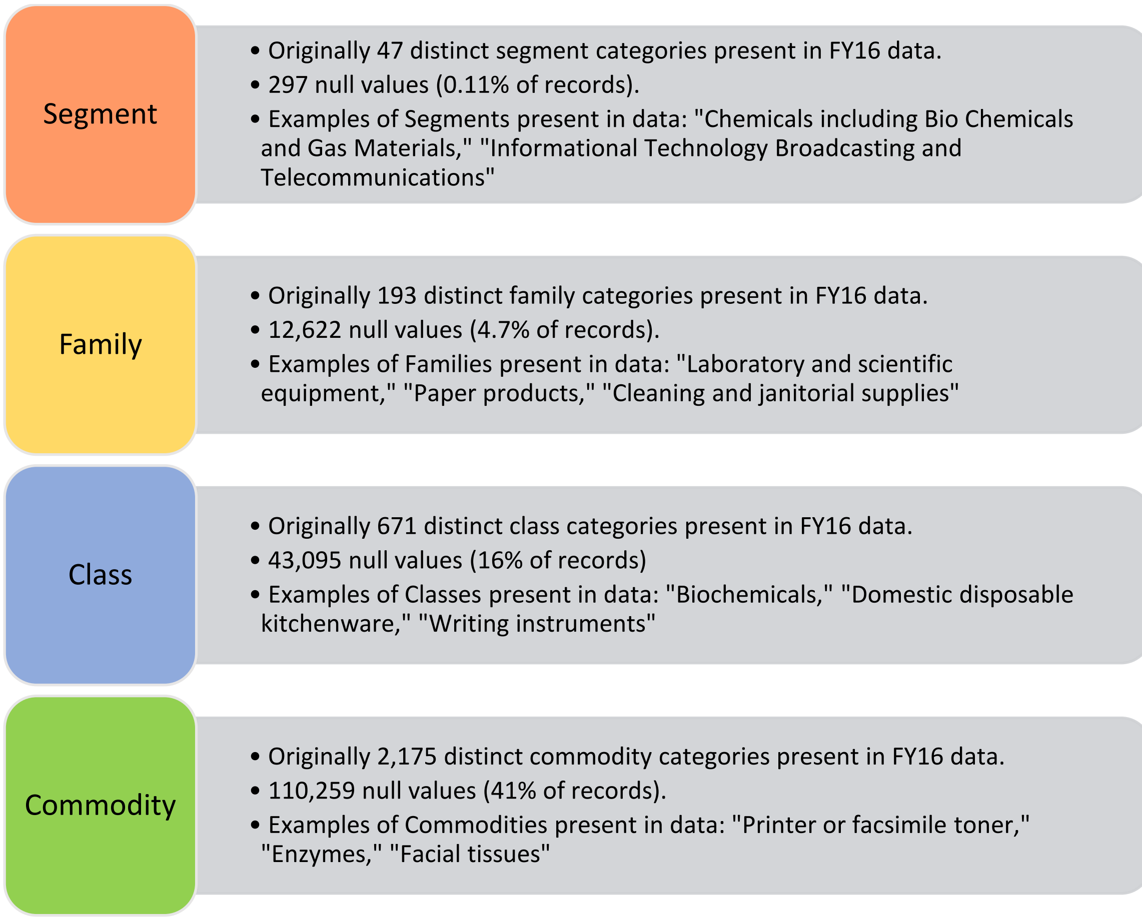


Figure 10: The statistics of ECAT purchase records categorized by UNSPSC levels. Note the number of null (empty) values.

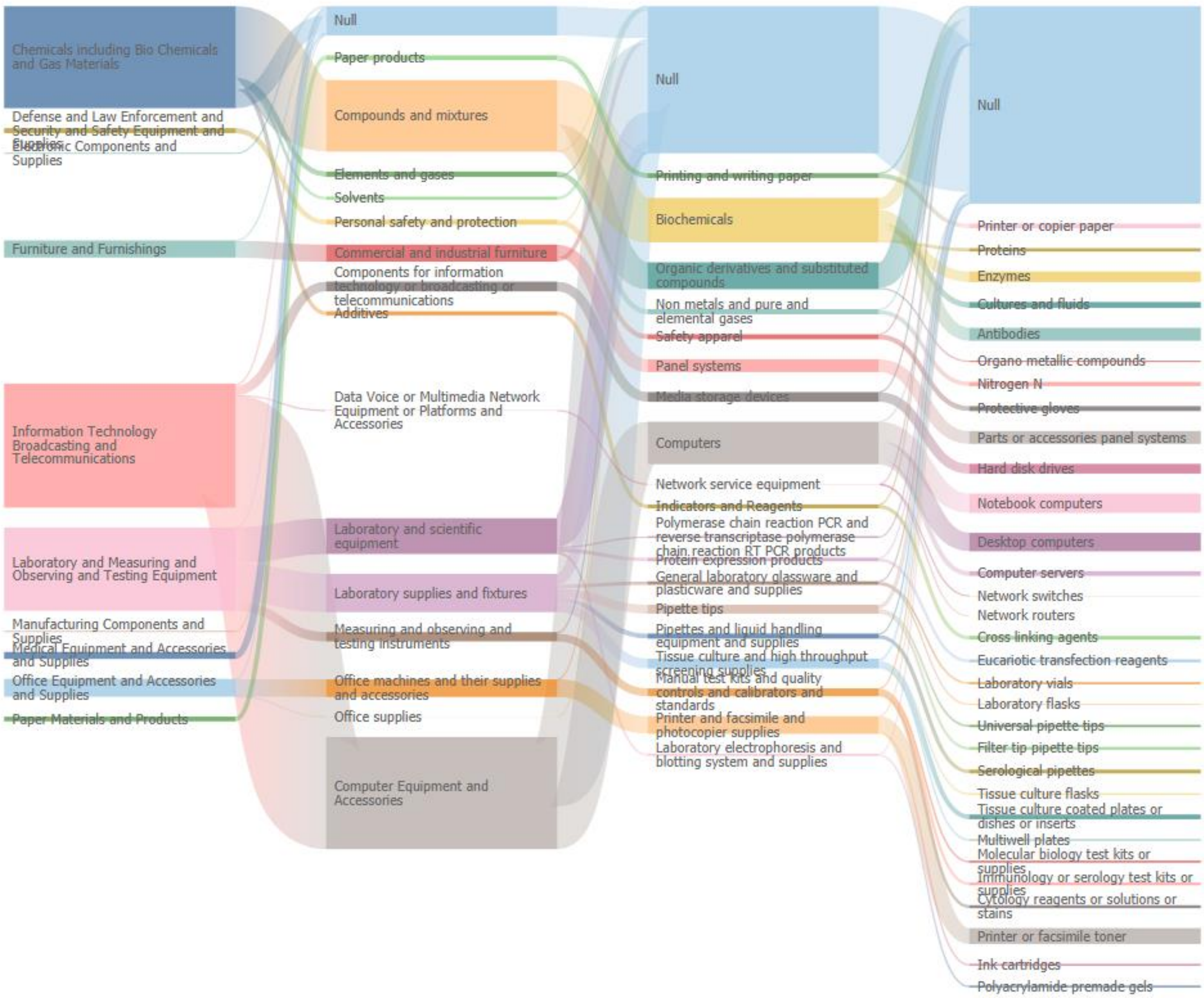


Figure 11: A Sankey diagram showing a sampling of FY2016 ECAT data by UNSPSC Segment, Family, Class, and Commodity. Only the highest-spend categories are included in this figure, for the purpose of readability. All empty values are indicated by "Null."

The Sankey diagram in Figure 11 shows only a sampling of the UNSPSC categories present in the data – specifically, the highest-spend categories are included. As can be seen from the large blue nodes entitled "Null," a large percentage of the Family, Class, and Commodity categories were empty, or unspecified.

Having fully specified UNSPSCs is much preferred for the purposes of a MFA; if each purchase contains a known Commodity, a total count of like-products can be obtained. Furthermore, knowing commodity-level specificity provides more information for inferring material type and product weight (more information on this provided later in this chapter). However, we were presented with the obstacle that about 41% of our data lacked a Commodity level category. Therefore, we sought a way to assign the empty rows a commodity level categories.

Method for Classifying Unspecified Purchases

To classify unspecified UNSPSC fields, help was solicited from Ricardo Lopez, a MIT student studying computer-science. Together, we used natural language processing of the ECAT data to classify unspecified purchases. The goal was to populate the data fields so that every record had a complete UNSPSC code that was specified through Commodity.

Lopez created a general algorithm for classification of unknown UNSPSC attributes. In addition, Lopez used Python to write the classifier scripts. First, the program read in a comma-separated values file (.csv) containing the full UNSPSC taxonomy, or UNSPSC list of hierarchical categories. The program stored a list of all possible Segment, Family, Class, and Commodity categories as a tree structure containing hierarchal branches. Next, the ECAT records were assigned unique record numbers for identification purposes, and then the records were read in by the program. Each record contained a specified UNSPSC category or Null for the four UNSPSC hierarchal levels.

To classify each UNSPSC level, the classifier selected a method to determine the category of the next branch. The method was selected in the following order:

1. If the category is known (i.e., already specified by the original data), use that category.
2. If the category is unknown (i.e., Null), use the following methods to assign a category to that UNSPSC level:
    a. Run the **Word-Matching Algorithm** (described below) to identify the UNSPSC category that mostly closely matches the product description.
    b. Assign a **random** UNSPSC category from that branch.
    c. Apply a **hard-coded classification rule** (described below), created by the author, to assign a particular UNSPSC category for records that contain particular product descriptions.

<u>Classification using the Word-Matching Algorithm</u>

The custom Word-Matching Algorithm involved the following steps:

1. Process the Product Descriptions. The product descriptions contained messy strings of text that were inconsistent, which necessitated text processing. First, the product description strings were parsed into words (based on the location of spaces, commas, periods, etc.). Then, non-English words were identified from the product descriptions by comparing the parsed words to an English dictionary using a dictionary module in Python. Non-English words were removed from the product descriptions. Examples of the most common non-English parsed strings were abbreviations, product numbers, and proper nouns.
2. Next, numbers and insignificant words, such as “and,” “the,” “by,” and “with” were removed from the product descriptions, since these words are not useful for

determining a classification. This list of insignificant words was created by Perlman and Lopez by reading product descriptions and noting the filler words. For example, if the product description was originally “8 by 12 copy paper,” it would be processed and re-named as “copy paper.”

3. The script stored the product description tokens. In the example above, the two tokens would be “copy” and “paper.”
4. The program created a classification tree with 4 levels. Each level corresponded to a level in the UNSPSC classification structure. The highest level was Segment, and bottom level is Commodity.
5. The program identified all records containing unclassified UNSPSC values.
6. To classify, the script start at the top level to choose a Segment. It chose a Segment from the available list. The chosen Segment was the Segment that shared the most tokens with the product description. Using the same example from Step 2, the algorithm would choose ‘Paper Materials and Products’ since that Segment shares one token with the product description which is “paper.”
7. The script continued classification for Family. This is the same process as before, but now only involves choosing from the set of Families within the Segment from Step 4.
8. The script applied this method to the Class and Commodity branches to complete the classification.

Applying Natural Language Processing to Compare Like-Products

The classification tree was also designed to store the tokens from full classified records. For example, one record with product description was “Apple TV with Cable Box’ might have an existing Segment classification of “Domestic Appliances and Supplies and Consumer Electronic Products,” a Family of “Consumer electronics,” Class of “Audiovisual equipment,” and Segment of “Televisions.” Consequently, in our classification algorithm, that “Segment of Domestic Appliances and Supplies and Consumer Electronic Products” would store the tokens ‘apple’, ‘tv,’ ‘cable’, ‘box.’ (The ‘with’ would not be stored, since it is not helpful.) The classified Family, Class, and Commodity would also store the tokens. Storing those tokens helps retain knowledge of product similarity. Instead of only comparing the amount of similar tokens between Segment titles, similar tokens can be drawn from previous training examples.

Random Classification

In the minority of cases, the classifier was unable to use the word-matching algorithm because the product description was sparse or contained unusual words. In these cases, the list of stored product description tokens contained few meaningful tokens, and there were zero tokens that matched the UNSPSC tokens. Consequently, a random classification choice, within the particular tree branch/level, was chosen using a pseudo-random selection functionality within Python.

Hard-coded Classification Rules

A handful of “hard coded rules,” created by Perlman and implemented by Lopez, were generated to assign specific product descriptions to specific UNSPSC Commodities. These rules were implemented as a result of the human verification of the word-matching algorithm. If the algorithm consistently assigned a particular type of product description incorrectly, a hard-coded rule was created to correct this misidentification. These rules superseded any previously assigned classification. Table 2 shows a small sampling of pairings of Product Descriptions and UNSPSC Commodities that were matched by Perlman. These matches were incorporated into the classification script as hard-coded rules, using conditional statements. For instance, the script implements conditionals like: "If the Product Description is 'Apple Mouse-Usa,' then assign the UNSPSC Commodity to 'Computer mouse or trackballs.'"

Table 14: A sampling of pairings of Product Descriptions with UNSPSC Commodities that served as the basis for hard-coded classification rules.

Product Description	UNSPSC Commodity Identified by Perlman
Apple Mouse-Usa	Computer mouse or trackballs
Moshi Clearguard Cs Keyboard Cover-Usa	Equipment cases
G-Tech 12tb G-Speed Q Usb3/Fw/Esata-Caf	Hard disk arrays
Logitech Wireless Solar Keyboard Gry-Usa	Keyboards
Airport Time Capsule 802.11ac 2tb-Usa	Network routers
Ipad Air Smart Case Black-Zml	Notebook computer carrying case
Mbair 13.3/	Notebook computers

Verifying Accuracy of the Classifier

To assess the accuracy of the classifier, a sample of purchase records (rows) were excluded from the pool of data used for training the classifier, and instead were used to verify the accuracy of prediction. The classifier was tested on these records, and the predicted classification for each UNSPSC was compared to the true classification. The accuracy for predicting segment was over 90% and the accuracy of predicting commodity was over 70%.

Potential Improvements

The natural language processing method used in classify previously known UNSPSC categories was effective, but could be improved. Additional information could be considered when creating a classifier. In our method, only the product description was taken into account to make an identification decision. However, more information, such as supplier, manufacturer, or price could be considered and added as "features," in addition to similarity as quantified by common tokens. This would require having complete data for those fields, as well as additional analysis of how those fields function as predictors of UNSPSC categories. In this scenario, each feature could potentially be incorporated probabilistically. With more time, machine learning techniques could also be applied to the classification process. It is possible that machine learning might produce better inferences than our rules-based classifier.

Attempt to Assign ECAT Records Material Categories and Product Weights

Assigning Material Categories

The original goal of the work with Lopez included mapping ECAT purchases to material types contained in the University-Specific Material Taxonomy (USMT), described in Chapter 2. The USMT has multiple levels of specificity, similar to the UNSPSC product taxonomy. Therefore, we tried to apply a modified version of the word matching UNSPSC classifier to the challenge of material identification. Instead of the identification choices being product types (e.g., stapler), they were material types (e.g., steel).

We found that material identification was significantly more difficult to accomplish with the data available. The main problem was that the product descriptions, as well as data in other fields, contained very few words that were related to material type. This gave the classifier very little information to use for the decision tree, leading to a high fraction of randomly assigned material types.

To assess the classifiers accuracy, we extracted a sample of 100 purchase records and reviewed how well the classifier had selected a material type from the material taxonomy. We estimated that, of the 100 records, only 27 were correctly identified and that 3 records were close to correct. This verification sample suggests that the material identification classifier was accurate less than 30% of the time. The records identified correctly almost always contained the material name in the Product Description – for instance "OX 300: Industrial **Oxygen** Size 300 Cylinder" or "Gloria Jean's Hazelnut **Coffee** K-Cup Packs, 24/Bx." Due to limited resources and no ability to obtain more detailed information about the products, we halted the effort to identify the material type of purchases based on ECAT data.

Assigning Weights/Masses

Our method for inferring the mass of products relied on first having relatively accurate material identification, since we planned on using market prices of materials ($/kg) to infer mass. However, since we could not consistently identify materials of the purchases, this strategy was not feasible. Consequently, we were unable to design an efficient, or automated, method for estimating mass flows of purchases by simply using the data provided by Procurement. An inefficient alternative would have been to hard-code weights per product based on product description or UNSPSC.

As a result, the only way efficient way to estimate mass of purchased products would be to use external data. For instance, it might be possible to gain access to an external data set of product weights from manufacturers or distributers, and merge this data by product number or product description. This might be an avenue of future research for others repeating the MFA MIT, or for another university that has similar purchase record data.

Learnings from Data Processing

The purpose of analyzing the ECAT purchase records was to characterize purchases made by the university. Because the data collected on purchases was primarily for Procurement accounting, we were challenged with the task of creatively processing the data for a new application. Despite that the original purchase record data was incomplete, the data set was still highly useful for understand product flows. This analysis revealed that data processing of purchase records is challenging, but necessary, for understanding a university's material inputs.

Until this study was done, Procurement data was mostly analyzed at an aggregated level. This dissertation's analysis required more depth, breadth, consistency and completeness in the data than has ever been captured. Furthermore, some of the data required for our analysis is not typically relevant for processing a financial transaction. Consequently, looking forward, we need new strategies to incorporate additional data at the source for multiple uses, not only for financial processing. This would strengthen the relationships between academic, administrative and operational arms of MIT.

Some useful lessons were learned as a result of the data processing described in this chapter. First, we demonstrated that purchase records collected by a university's procurement office can be useful for doing a product flow analysis or a commodity-specific analysis. However, they cannot easily be used for material flow characterizations, because material-related information is typically absent. Second, our analysis showed that even when product-specific descriptions are mostly filled in, natural language processing is limited in its ability to predict product type. Even with about 41% the purchase records having fully-specified UNSPSC classifications, a classifier utilizing natural-language processing was still often unreliable for inferring the Null classifications. Third, we found that product weight, or mass, is difficult to infer for purchase records unless the university collects data on shipping weight or product weight. These weights may be obtainable from the vendor.

Chapter 4: MIT Material Flow Results

Chapter 4 Abstract

This chapter summarizes the estimated material inputs to, stocks within, and outputs of MIT, which were determined using the methods described in the previous two chapters. Inflows and stocks were characterized using financial data, and waste flows were quantified using mass data. Flows were characterized using a combination of product/commodity descriptors and materials. Material purchases were characterized by product category, temporal variation, purchasing unit/entity, and level of decentralization. The top five purchase categories (by spend) in descending order are: (1) laboratory supplies; (2) hardware purchases/maintenance; (3) laboratory equipment; (4) chemicals, reagents & gases; (5) office furniture. The chapter also reports the largest stocks of durable goods by quantity and dollar value, as well as the average residence time, or lifetime, of different products. The chapter also catalogues the quantity and disposal/recycling destinations of different waste streams, including municipal solid waste, single-stream recycling, hazardous waste, medical waste, and radioactive waste.

Inflows

Overview of Inflows

As discussed in Chapter 2, this thesis utilizes two different datasets of purchase records – one covers the full scope of purchases made in FY16 but provides less detail, and the other only covers purchases made via the Electronic Catalog (ECAT), but contains greater detail. Neither dataset had been used before for a material flow analysis, or anything similar.

Based on the centralized procurement data, the best estimate of total purchased goods for FY16 is $187.5 million. In that one year, 488,238 individual purchases were made. The average purchase price per order was $384, and the median was $174. The largest individual purchase orders were between one and six million dollars – some of these included purchases of drugs and pharmaceuticals and IT hardware and network equipment. Other large purchases included research specimens for cancer research, office furniture for the department of facilities, and laboratory equipment.

Specifically within ECAT, total purchased goods for FY16 were $37.5 million. In that year, 268,816 individual purchases were made. The average purchase order price was $139, and the median was $39. The largest individual purchases were for computers and servers.

Mass Estimates for a Selection of Purchased Commodities

As explained in Chapter 2 and 3, estimating mass quantities for all of the university's purchased goods was not possible due to the data's limitations. However, presented below is one collection of mass-flow estimates. A small group of commodities that was frequently purchased via ECAT were selected and manual calculations of their mass were performed. Because the process for doing these manual calculations was laborious and the result was not verifiable, the resulting mass values should be viewed as gross estimates, and the process should be viewed as a proof-of-concept.

Specifically, the method for estimating mass was the following:

(1) Identify a list of commodities that are frequently purchased by the university (in this case using the electronic catalog).
(2) For each commodity, identify the form factor/unit size/specific product that is most commonly purchased.
(3) Search for the weight (mass) of a given product by researching the specifications of that particular form factor/product. Do this by using one or more of the following methods:
    a. Use Staples' product list which includes weights for many office supply products.
    b. Search for the product weight online by looking up Product Numbers or Stock-keeping Unit (SKU).
    c. Use information contained within the product description in ECAT that references volume or weight.
(4) Use the best estimate of mass for the most common product within that commodity and assign that mass as the average mass for one unit of the commodity.
(5) Multiply that mass/unit by the number of units purchased to estimate total mass.

This method was used to estimate the masses of the commodities listed in Table 15. For instance, it is estimated that in FY16, MIT purchased 132 MT of nitrogen gas, 82.6 MT of printer paper, and 2.66 MT of notebook/laptop computers.

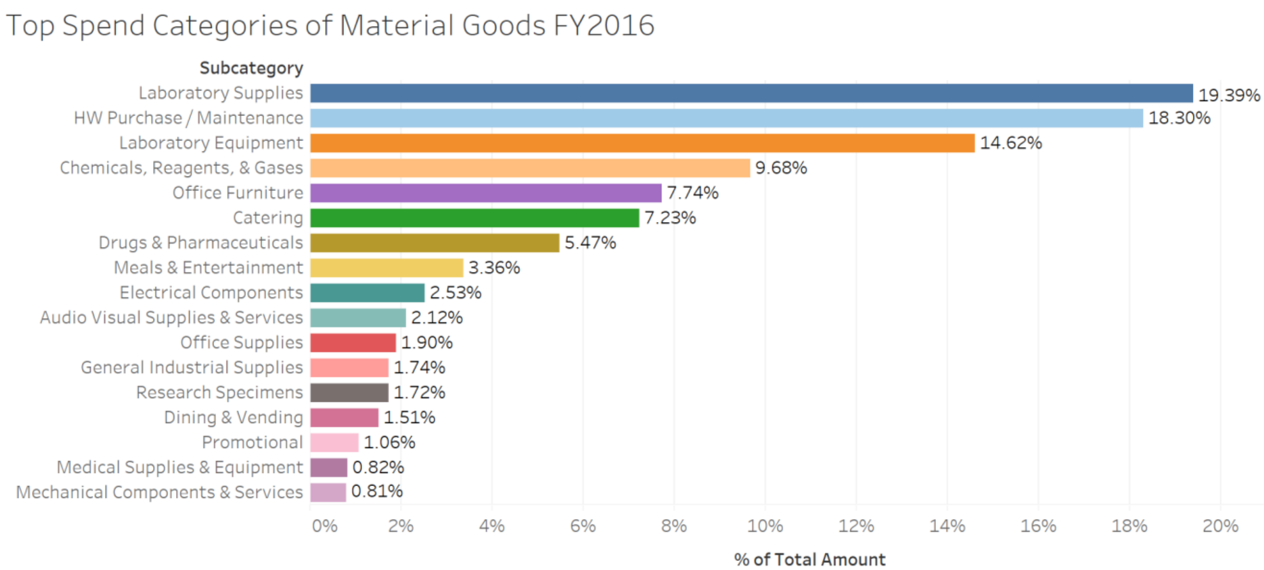
Table 15: Mass flow estimates for a sampling of commodities purchased by the university.

COMMODITY TYPE (FROM ECAT)	ESTIMATED NUMBER OF UNITS	PER-UNIT ESTIMATED MASS (KG)	TOTAL MASS (MT)
Nitrogen (N)	3,299	40	131.96
Oxygen (O)	683	124.5	85.03
Printer or Copier Paper	3,643	22.7	82.62
Argon Gas Ar	590	89.6	52.86
Carbon Dioxide Gas (CO_2)	746	22.7	16.93
Soft Drinks	1,095	9.35	10.24
Printer Or Facsimile Toner	5,653	1.5	8.48
Paper Pads Or Notebooks	2,766	2.3	6.36
Filter Tip Pipette Tips	1,664	3	4.99
Desktop Computers	801	6	4.81
Organic Halogenated Compounds	3,337	1.33	4.44
Task Seating	168	24.5	4.12
Helium Gas (He)	457	9	4.11
Laser Printers	224	18.2	4.08
Universal Pipette Tips	1,014	4	4.06

Domestic Disposable Dishes	993	4	3.97
Folders	1,541	2.4	3.70
Tissue Culture Coated Plates or Dishes or Inserts	1,825	2.0	3.69
Paper Towels	861	3.65	3.14
General Purpose Cleaners	881	3.4	3.00
Notebook Computers	1,662	1.6	2.66
Facial Tissues	1,858	0.95	1.77
Ink Cartridges	1,589	0.93	1.48
Protective Gloves	2,940	0.45	1.32
Alkaline Batteries	1,940	0.68	1.32
Self-Adhesive Note Paper	1,220	0.91	1.11
Centrifuge Tubes	1,348	0.59	0.80
Coffee	2,534	0.25	0.63

Analysis by Product Category

For the university's total purchases during FY16, ten product categories consist of 84% of the material good spend. The top five spend categories in descending order are: (1) laboratory supplies; (2) hardware purchases/maintenance; (3) laboratory equipment; (4) chemicals, reagents & gases; (5) office furniture. The largest spend categories are shown in Figure 12; spend in each of these categories was at least $758K.



% of Total Amount for each Subcategory. Color shows details about Subcategory. The data is filtered on Subcategory (group), which keeps Goods by subcategory. The view is filtered on Subcategory, which keeps 30 of 124 members.

Figure 12: The top categories of spend on material goods in FY16, presented by percentage of total spend. The largest spend categories are Laboratory Supplies, Information Technology Hardware (i.e., HW Purchase/Maintenance), and Laboratory Equipment.

Figure 12, above, provides the most aggregated view of the material goods spend by product type using the full FY16 purchase records (which contain no product-specific detail). In contrast, Table 16 shows the information about purchased products in a high-resolution or highly detailed way; it uses ECAT data to provide the list of commodity-level products with the highest total spend. These commodities are standard commodities that can be found in the UNSPSC database (described in Chapter 3). Although the ECAT purchase records only show a subset of purchase types, this cross-section is still revealing. It also provides a floor estimate for number of units of a given product purchased on campus – it is almost certain that the real total number of units purchased is significantly higher for products that are frequently purchased via other channels such as credit card and purchase orders. As shown by Table 16, the commodities accounting for the largest spend are: laptop computers, desktop computers, antibodies, and printer toner. Given the high cost of computers, the number of purchased units is lower than it is for some of the other commodities listed. There were a high number (9,962) of individual purchases of paper - be it reams or cartons. The same is true for printer toner, protective gloves, and culture (used for biological experiments).

Table 16: A list of the commodities with the highest total spend in ECAT in FY16.

Commodity	Ranking of Expenditure via ECAT During FY16 (Descending in Order)	Quantity (Number Of Units)
Laptop Computers	1	2,417
Desktop Computers	2	1,441
Antibodies	3	5,476
Printer or Facsimile Toner	4	7,349
Parts or Accessories Panel Systems	5	5,006
Enzymes	6	6,356
Docking Stations	7	3,290
Cultures and Fluids	8	7,393
Hard Disk Drives	9	2,379
Mouse Pads	10	449
Tissue Culture Coated Plates/ Dishes / Inserts	11	3,476
Proteins	12	1,651
Cross Linking Agents	13	1,525
Protective Gloves	14	7,884
Printer Or Copier Paper	15	9,962
Computer Servers	16	48
Aliphatic Solvents	17	2,644
Network Switches	18	79

Figures 13-16, below, provide another way to segment ECAT purchasing by product category. Each of these figures shows purchasing at multiple levels of disaggregation using Sankey diagrams. These diagrams display purchase quantity as lines (or arrows), where the line thickness is proportional the expenditure for that category. Each of the four figures shows the types of commodities found in a different general product category. Figure 13 shows laboratory equipment and supplies; Figure 14 shows chemicals, biochemical, and gases; Figure 15 shows information technology and telecommunications products; and Figure 16 shows furniture and furnishings.

Laboratory Equipment and Supplies

General Product Category

Commodity

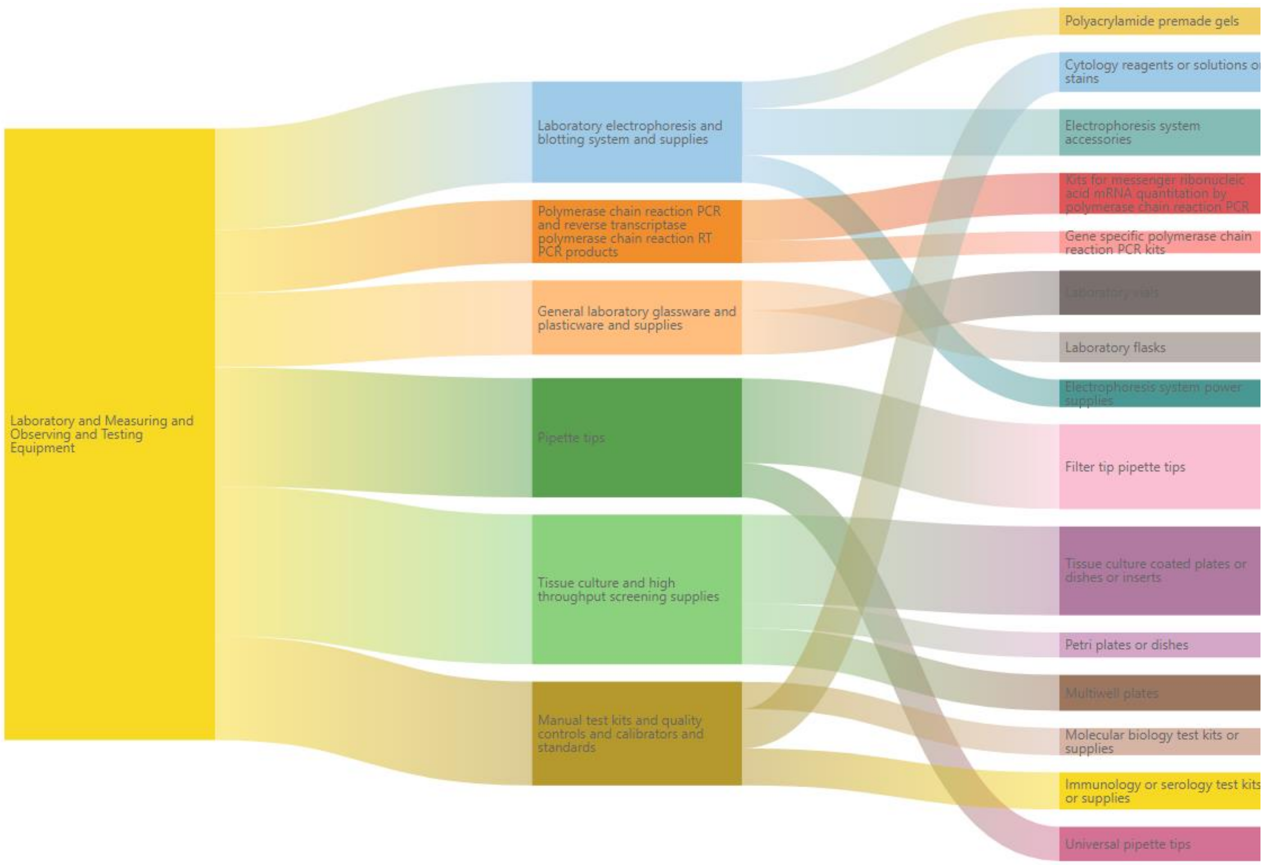


Figure 13: The classification of FY16 ECAT purchasing of **laboratory equipment and supplies** by specific commodities (e.g., pipette tips, petri dishes, etc.). The width of the stripe is proportional to the expenditure ($).

Chemicals, Bio-chemicals, and Gases

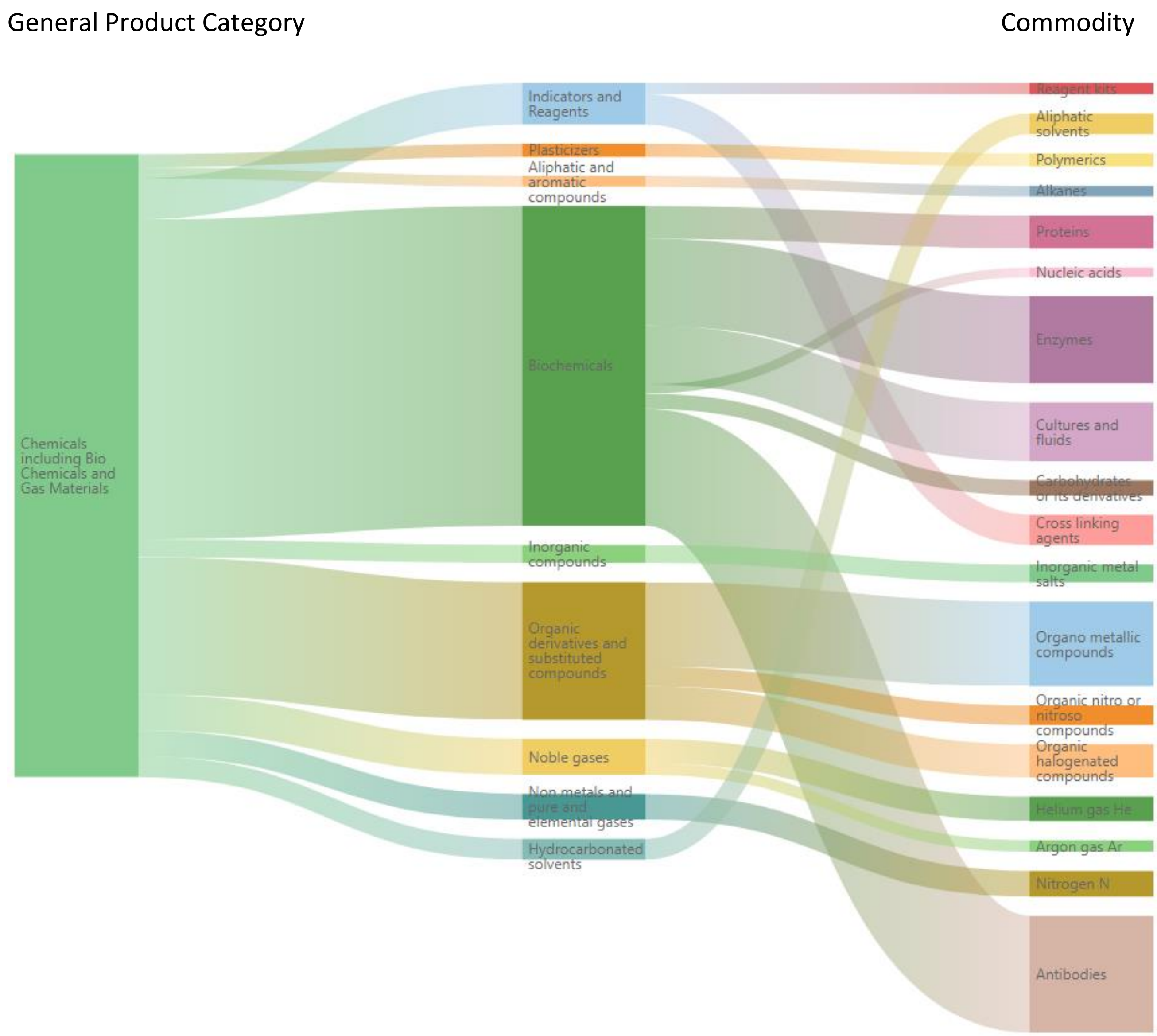


Figure 14: The classification of FY16 ECAT purchasing of **chemicals, biochemical, and gases** by specific commodities (e.g., enzymes, antibodies, etc.). The width of the stripe is proportional to the expenditure ($).

Information Technology and Telecommunications Products

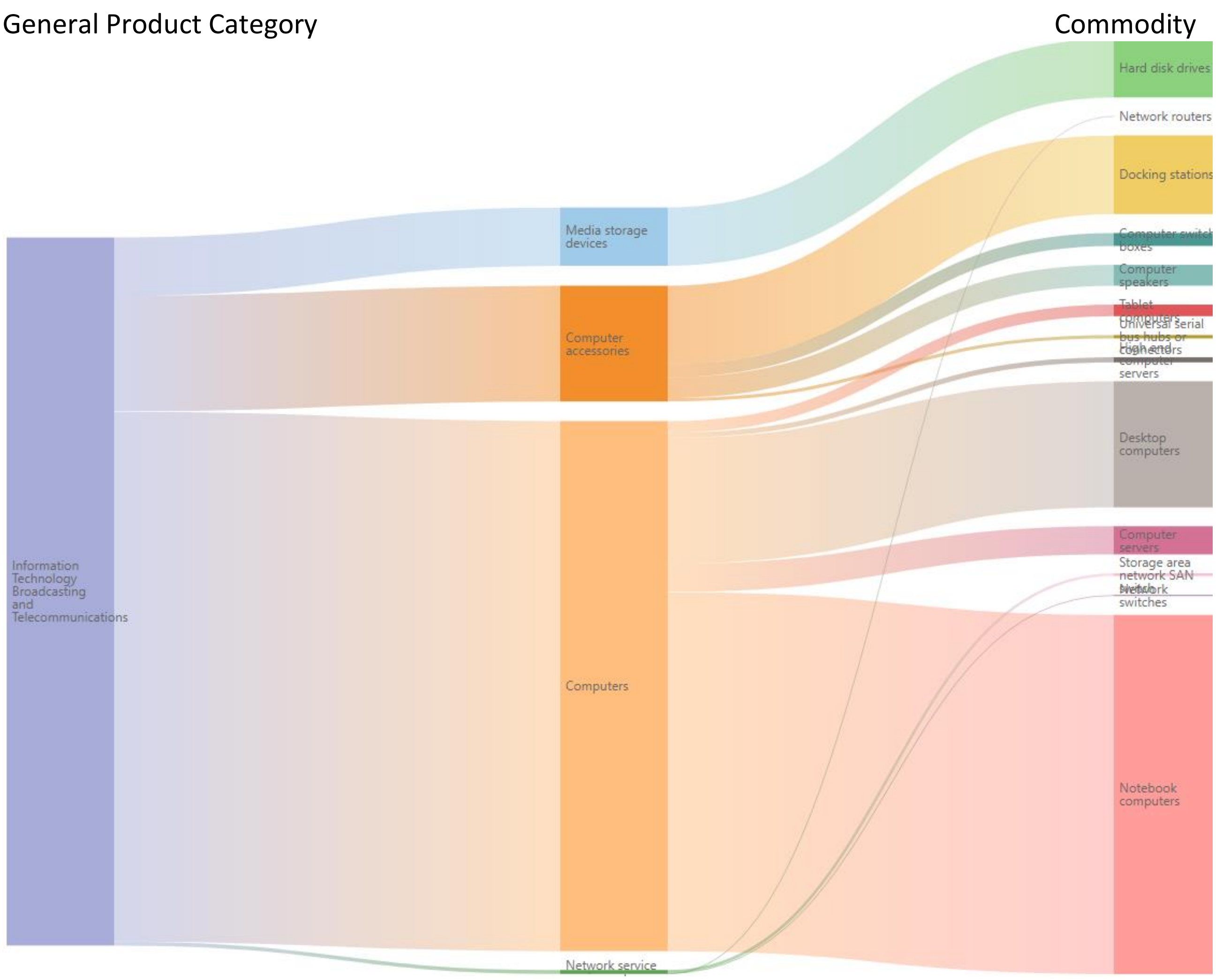


Figure 15: The classification of FY16 ECAT purchasing of **Information Technology and Telecommunications Products** by specific commodities (e.g., notebook computers, hard drives, servers, etc.). The width of the stripe is proportional to the expenditure ($).

Furniture and Furnishings

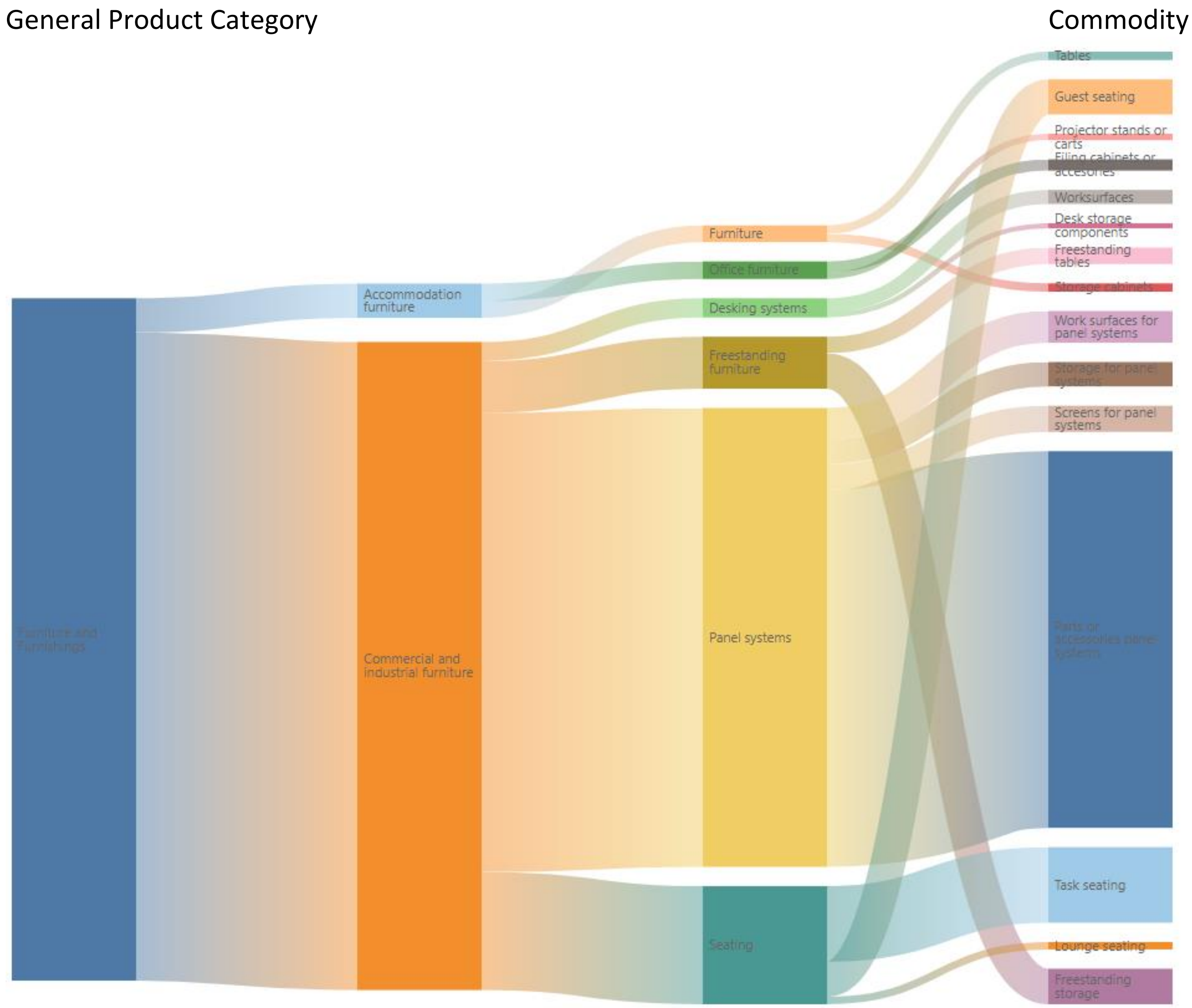


Figure 16: The classification of FY16 ECAT purchasing of **Furniture and Furnishings** by specific commodities (e.g., task seating, tables, etc.). The width of the stripe is proportional to the expenditure ($).

Temporal Variation of Purchasing

A review of annual ECAT spend between FY2010 and FY2016 shows that the university is spending more on material goods each year. As Figure 17 shows, spend increased from $30.3 million to $37.6 million over six years. This is a 24% total increase. The annual percentage increase ranged from 0.4-7.5%, and was often greater than the rate of national inflation during that time period (which ranged from 0.1-3.2%). Most of the growth in expenditure over the seven year period is due to an increase in purchasing of (1) chemicals, biochemical, and gas, and (2) laboratory equipment. Based on this trend, it can be expected that MIT's online material goods purchasing will continue to increase each year for the foreseeable future, unless there are major economic or behavioral changes.

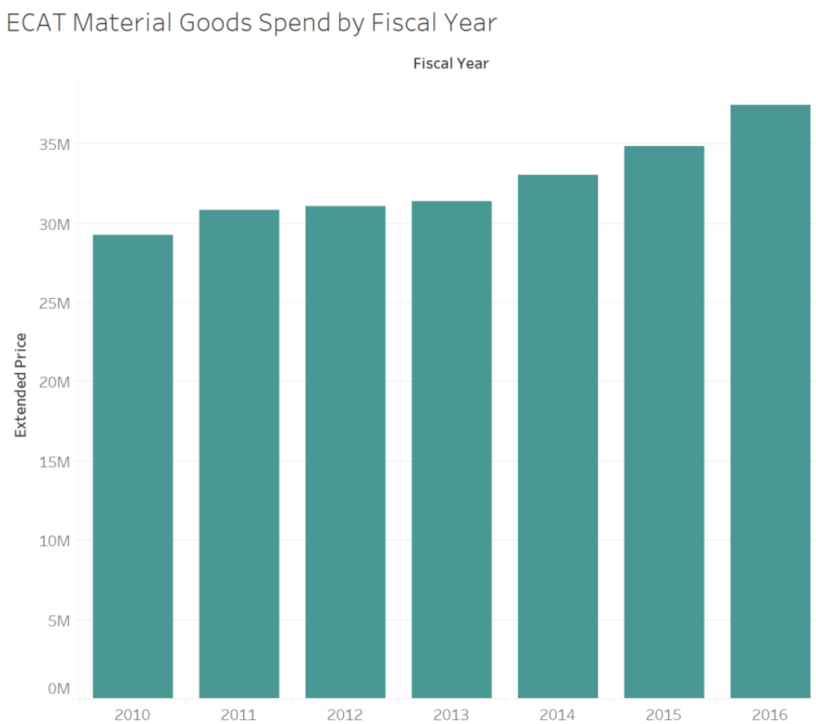


Figure 17: Spend on material goods via the Electronic Catalog for each fiscal year (2010-2016).

At the monthly scale, ECAT purchases varied, but with few repeated patterns. The one common occurrence was that November and December tended to be months with a lower spend amount and lower number of purchases. Given that this dip in spending occurs during the last week in November and the last two weeks of December, the reduced purchasing is logically associated with holidays and office closures.

When the full "universe" of FY16 purchase data (beyond ECAT) was assessed for monthly variation, a slightly different pattern was found. As shown in Figure 18, total purchasing was lower in the months of September, January, and May, particularly for the purchase of catering, chemicals, and pharmaceuticals. It is unknown why expenditure on purchases is lower for these months.

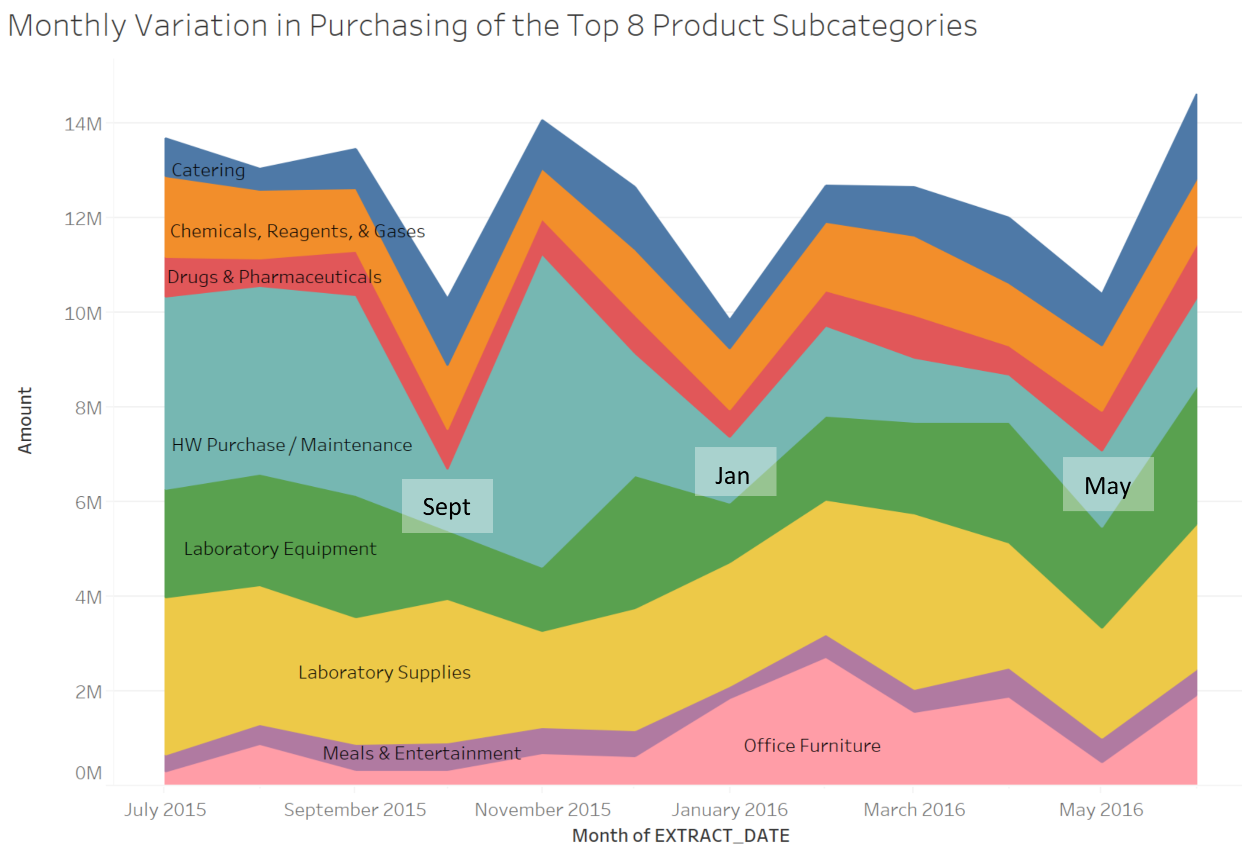


Figure 18: Monthly variation in purchasing of the top eight product subcategories for FY16 (total university spend).

The full scope of material goods purchasing (including purchase orders, etc.) was also analyzed at the weekly scale during FY2016. As shown in Figure 19, there are significant variations at the weekly scale. At the daily scale (not shown), there is a drastic decrease in number of purchases and spend on weekend days (Saturday and Sunday), which is unsurprising. However, there is still some amount of purchasing on the weekend. Of the weekdays, there is slightly more purchasing on Tuesdays, and slightly less on Fridays.

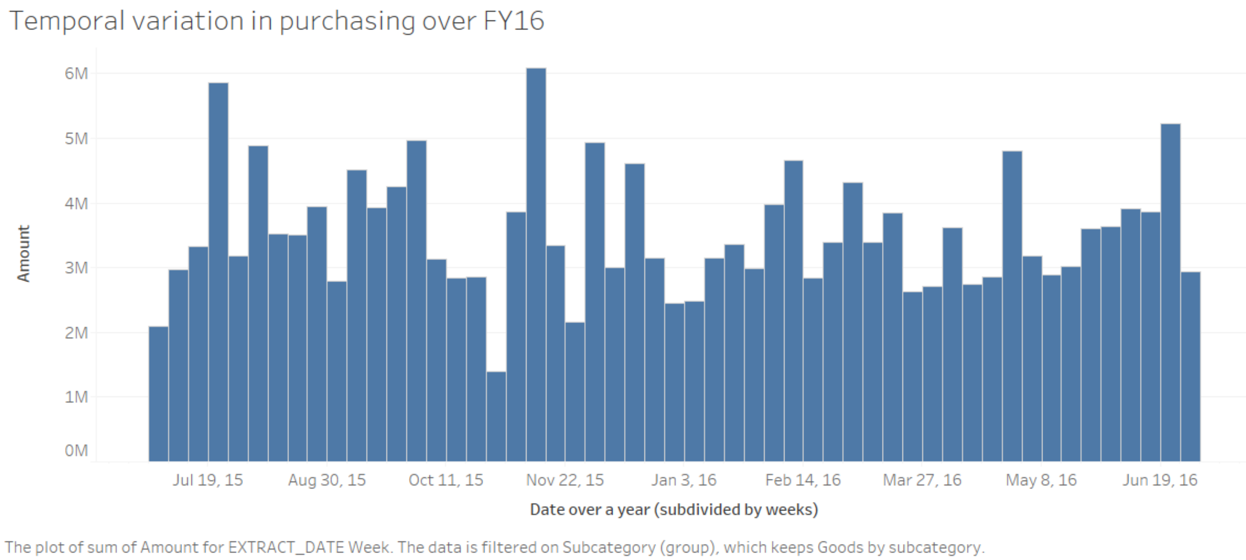


Figure 19: Weekly spend on material goods for all of MIT during FY2016.

Purchases by University Organizational Unit

MIT has over 400 Departments, Labs, and Centers (DLCs). DLC is a catch-all term to indicate an organizational unit at MIT.

The organizational units that had the largest spend on material goods for FY16 were operational units (as opposed to academic, research, or administrative).

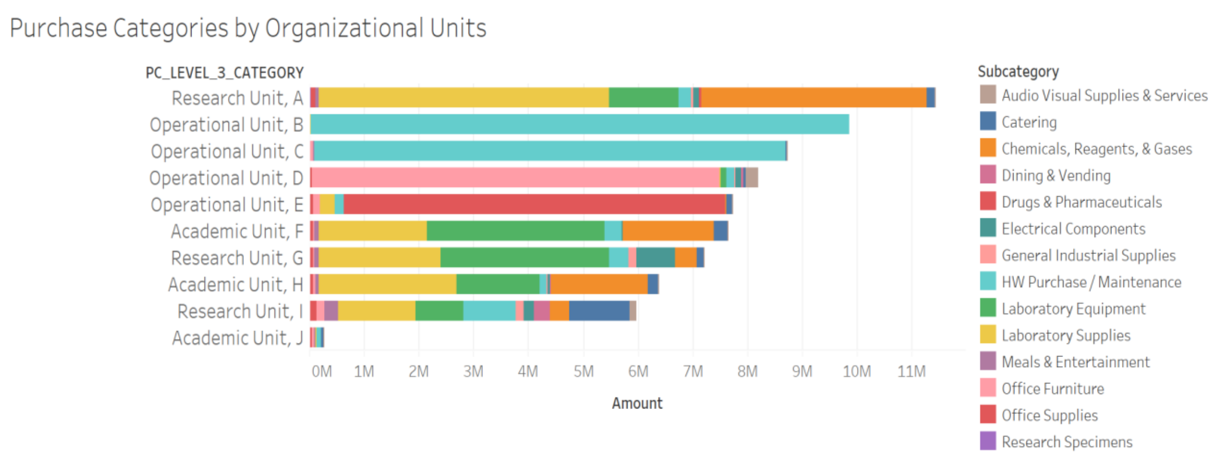


Figure 20: MIT's organizational units with the highest expenditure on material goods. The most prominent product categories are shown for each organizational unit (delineated by color).

The colors in Figure 20 indicate product category of purchasing. Some organizational units' purchasing is dominated by one single product type; this is the case for the two operational units which are part of MIT's Informational Technology (Telephone & Network Services Center and Enabling Services), both of which mostly purchase IT hardware. Office furniture is the dominating spend category for the Department of Facilities; this is likely because Facilities often procures furniture for campus buildings, especially if there is a renovation being done. In contrast, one interdisciplinary laboratory is example of an organizational unit with a relatively diverse “portfolio” of material goods purchasing – the center buys a mixture of laboratory supplies, electronics, catering, research specimens, and chemicals. Figure 20 also shows how some product categories are bought by a wide variety of organizational units; catering is purchased by most units, and lab supplies and lab equipment are fairly ubiquitous between research groups in the sciences.

MIT’s ECAT purchasing by organizational unit and product category is shown in Figure 21, which is a Sankey diagram showing the relative quantity of purchased goods by MIT purchasing unit. From this figure, it can be seen that almost all of the schools and large entities buy paper, furniture, office supplies, and IT equipment, for instance. The majority of lab equipment and supplies is consumed by the schools related to science, engineering, and laboratories conducting scientific research.

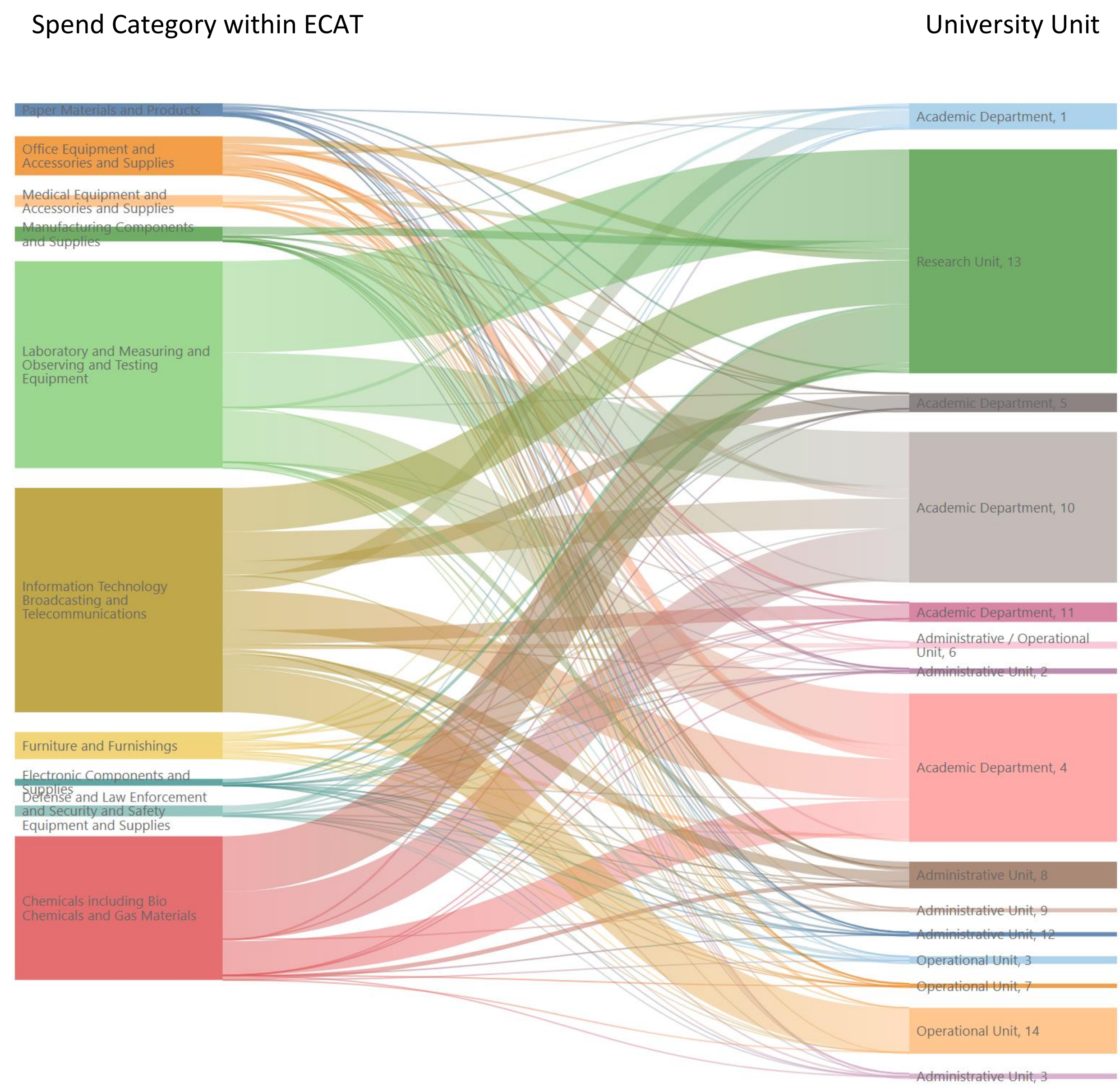


Figure 21: A Sankey diagram showing the relative quantity of purchased goods (in ECAT FY16) by MIT purchasing unit.

Level of (De)Centralization

Not only does MIT consume a large diversity of products, but a large number of individuals make those purchases. In other words, purchasing is done by many, rather than by a few select individuals; this indicates that the purchasing process is decentralized.
It should be noted that the *purchaser* may be different than the *product user*, and therefore the ECAT dataset is not able to provide information about the number of users per product category/organizational unit, etc. However, the data is still useful for inferring behavior relating to purchasing.

Within the ECAT database, during FY16, there were 3,436 distinct individual buyers making purchases at MIT. That means over 15% of the 22,500 members of the MIT population made a purchase through the ECAT system. The number of total purchasers would be even greater if including the individuals making purchases through other channels (such as credit card or purchase orders). Purchases were made from 214 distinct "purchasing units." Purchasing units are organizational units such as academic departments, libraries, the museum, and the admissions office.

The nature of purchasing can be further characterized by comparing the number of individual purchasers within various product categories. The data shows that the number of purchasers varies between product categories. This data is visualized in Figure 22. In this figure, the x-axis shows the annual expenditure for a given product category. The y-axis shows the number of distinct buyers for a given product category. The plotted points in different colors represent various product categories (paper, furniture, cleaning supplies, etc.). Product categories in the upper right corner are ones with high spend and high decentralization of purchasing. Product categories in the upper left corner are ones with high spend and high centralization of purchasing.

The product categories purchased by the largest number of individual purchasers are (1) office equipment/supplies, (2) laboratory equipment, (3) chemicals, reagents & gases, and (4) IT and telecommunications. These categories all have between 1,600-1,800 different purchasers, each; these are universally common purchase categories at MIT. However, not all of these product categories represent the same magnitude of spend – specifically, the expenditure on office equipment/supplies is significantly smaller ($1.7M) than the other three ($8.1M-$11.3M). In comparison to the other three categories, office equipment/supplies is a smaller purchase area by spend, but a large purchase area by number of purchasers. One example of a purchase category with a relatively high expenditure and low number of purchasers is furniture & furnishings. That is, $1.9 million dollars-worth of furniture/furnishings was purchased in FY16 by only 530 individuals.

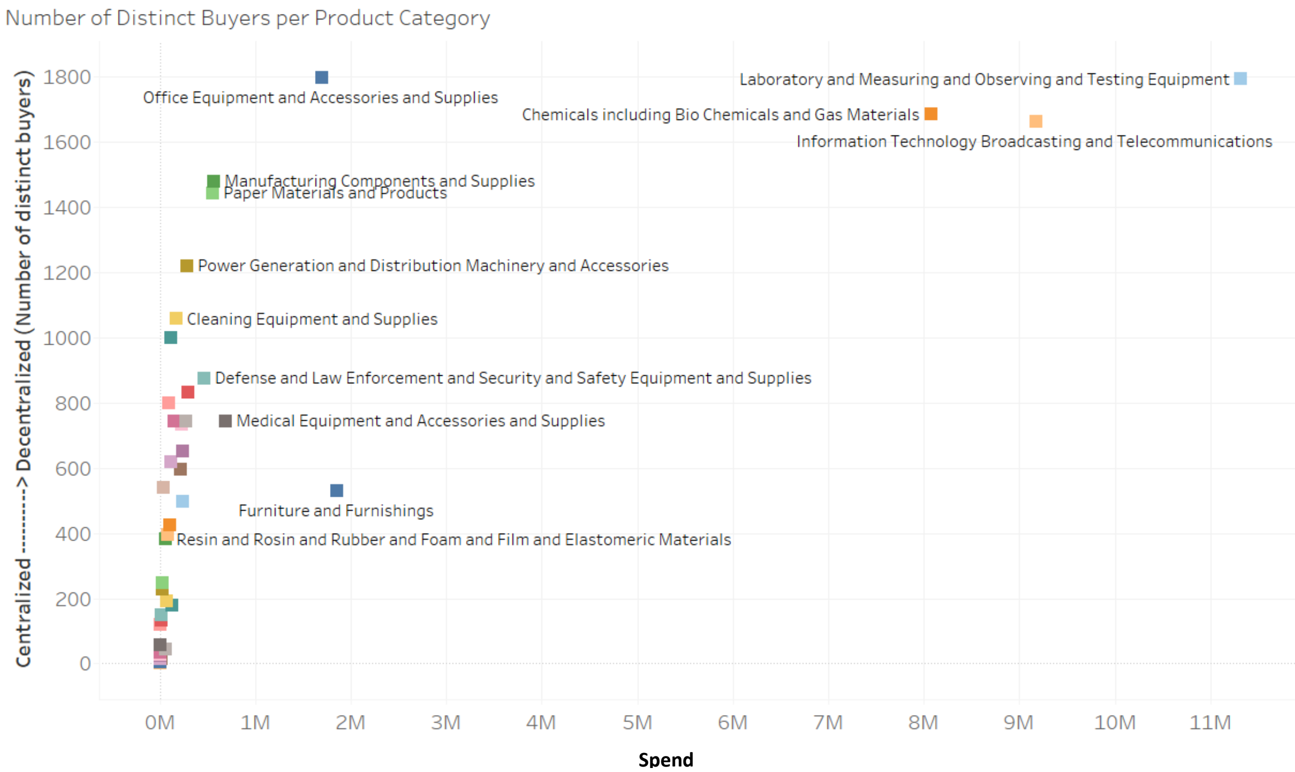


Figure 22: The number of distinct buyers per product category plotted in relation to the expenditure within that product category.

Expenditure per Capita and by School

As mentioned in the section Overview of Inflows (above), the total FY16 expenditure on material goods was $187.5 million. The MIT population is roughly 24,000 individuals, including students, faculty, and staff. As shown in Table 17, based on population, the average annual per-capita expenditure on material goods is estimated to be $7,756.

Table 17: Per-capita expenditure on material goods for the MIT population.

University Group	Campus Population
Undergraduate Students	4,527
Graduate Students	6,804
Faculty	1,067
Other Academic Staff	4,486
Research Staff	1,766
Administrative Staff	2,921
Support Staff	1,621
Service Staff	841
Clinical/Medical Staff	150
Total Population	**24,183**
Total FY16 Expenditure on Material Goods	**$187.6 million**
Average Per-Capita FY16 Expenditure on Material Goods	**$7,756**

Expenditure on material goods can also be assessed by school. As of FY16, MIT had five schools within the university: Architecture and Planning; Engineering; Humanities, Arts, and Social Sciences; Management; and Science. As shown in Figure 18, the expenditure varies significantly by school, as does the material spend per capita. The highest expenditure is the schools with the greatest number of students and faculty. Based on the number of students and faculty per school, School 5 has the highest expenditure on material goods per-capita. Given that MIT is a technical school with an emphasis on engineering and the sciences, and given that fields within these domains tend to be laboratory- and material-intensive, these results are unsurprising.

Table 18: Expenditure on material goods shown by MIT School and calculated per capita student and faculty.

					MATERIAL SPEND PER CAPITA		
MIT School (anonymized)	**Expenditure on Material Goods in FY16**	**Under-graduate Students**	**Graduate Students**	**Faculty**	**Per Student**	**Per Faculty**	**Per Faculty + Students**
School 1	$7.31 million	58	645	87	$10,400	$84,033	$9,254
School 2	$32.6 million	2,451	3,140	390	$5,824	$83,497	$5,445
School 3	$2.75 million	74	318	184	$7,020	$14,956	$4,777
School 4	$5.66 million	110	1,571	115	$3,366	$49,195	$3,150
School 5	$25.9 million	706	1,171	280	$13,799	$92,502	$12,008
Total	**$74,184,473**	**3,399**	**6,845**	**1,056**			

Stocks

As described in more detail in Chapter 2, the author used data on tagged property from MIT's Property Office to analyze stocks. This work demonstrates that data on assets/minor property, typically used for taxation and accounting purposes, can be used to characterize some stocks on campus. By working with this data, the author learned that this data is especially useful for estimating campus lifetimes of products and understanding use patterns, but is not necessarily sufficient for estimating the masses of stocks.

The author obtained the records of activations and deactivations entered during the fiscal years of 2009 through 2016. Over that period of time, there were 33,914 product activations and 47,415 product deactivations.

Characteristics and Quantities of Stocked Products

Each record in the database of tagged property (called E-Prop) contains a Use Status attribute that is classified as: active, disposed, government letter, non-inventorial, non-recoverable, return on asset, or unable to locate. The author obtained a list of records of tagged items that were purchased in FY2009-FY2016. As shown by Table 19, the majority of products purchased in that timeframe were still active as of 2016; this implies that the majority of property items have a campus lifetime of at least 1 to 6 years.

Table 19: Use status of products purchased 2009 and 2016.

2016 Use Status (of products purchased between FY 2009 and 2016)	Percentage by Count
Active	86.04%
Disposed	10.90%
Government letter (pending disposal with permission from government)	0.13%
Non-inventorial	0.04%
Non-recoverable	0.06%
ROA - FY 12	0.00%
ROA - FY 14	1.78%
ROA - FY 16	1.02%
Unable to locate	0.01%
Total	**100%**

The set of items classified as “active” (and purchased between 2009 and 2016) were used to characterize the stocks present on campus in 2016. Over 60,000 active tagged pieces of equipment (everywhere, server farms in Holyoke, Germany, Chile telescopes, International Space Station, etc.) were listed in the data set. Although not all of these items reside on campus, the majority do.

The total value (at time of original purchase, not including depreciation) of the active stock tracked by the Property Office is roughly $301.5 million. Table 20 shows some of the stock product types in which MIT has invested the largest amount of money. For instance, MIT owns many millions of dollars worth of servers, laptop computers, desktop computers, and lasers.

Table 20: Stock in the form of "active" tagged products that. This is a *partial list or sampling that* reflects the products that have the highest aggregate dollar value (listed in descending order).

Standard Product Name
Server
Laptop Computer
Desktop Computer
Microscope
Laser
Microscope System
Storage Device
Switch
Laser System
Mass Spectrometer
Analyzer
Network System
Array Processing System
Spectrometer
Scanner
Camera

Analysis of the Campus Lifetime of Stocks

When a piece of property is tagged, it is entered into the digital tracking system as an "active" item. Ideally, as soon as or soon after when the item is disposed of, given away, sold, or leaves campus in some other way, the item's status is changed to "disposed," and is given a "Disposition Type." Disposition types are further classified: abandoned, cannibalized, fellowships, deactivated, gift, loss, retired, returned for credit, scrapped, sold, stolen, traded, transferred to outside of MIT, transferred to sponsor. Table 21 provides descriptions of the possible Disposition Types, as used in this particular database system, called E-Prop.

Table 21: Disposition types and their descriptions for products tagged by the Property Office.

Disposition Type (No Longer Accountable On MIT Inventory)	**DESCRIPTION**
Abandoned	Government equipment that has been left at MIT, really old things that government doesn't want back. On campus still. Not accounting any more in inventory
Cannibalized	Taken apart to use the parts for something else. Usually for fabrications
Deactivated	End of useful life. Physically red-tagging. Could be recycled, trashed, obsolete
Fellowships	Purchased on a fellowship award, given usually to recipient of fellowship
Gift	Given away
Loss	Lost item
Retired	Usually gov't equipment, ask to retire it so can dispose of it
Returned for Credit	Returned for refund
Scrapped	Thrown out by user, who did not properly notify the Property Office
Sold	Sold
Stolen	Stolen, get police report
Traded	Traded in to a new purchase, ex. Cars or copiers
Transfer Outside MIT	e.g., researcher moves to another institution, and item goes with him/her
Transfer To Sponsor	Goes back to funding source

The most common form of disposal is vaguely described as "deactivated," which can mean a number of things. As shown by
Table 22, a significant portion of products (25%) are scrapped when they are disposed of, and 13% of products are transferred to a party outside of MIT. It should be noted that not all products that leave MIT leave as waste; rather, items that are sold or transferred likely go on to have a "second life" at another organization.

Table 22: Forms of disposal of products disposed of between FY2009-FY2016.

Disposition Type (no longer accountable on MIT inventory)	Count	Percentage
Abandoned	18	0.04%
Cannibalized	204	0.43%
Deactivated	26,402	55.68%
Fellowships	62	0.13%
Gift	426	0.90%
Loss	3	0.01%
Retired	1245	2.63%
Returned for credit	58	0.12%
Scrapped	11,902	25.10%
Sold	90	0.19%
Stolen	210	0.44%
Traded	357	0.75%
Transfer outside MIT	6,007	12.67%
Transfer to sponsor	431	0.91%

Using the Property Office database, the author analyzed the campus lifetime of products; she did this by subtracting the date something was purchased from the date it was disposed.

Table **23** shows a list of the average age (use lifetime) of a sampling of products. Due to having several data points per product type, we were also able to assess the variation in use lifetimes, which is captured by the standard deviation of the product age (last column of Table 4). Some notable findings regarding electronic equipment include that the average lifetime of laptops roughly 5 years, while desktop computers have a slightly longer lifetime of 6 years. Printers, projectors, and copiers, are kept for longer (10, 9, and 8 years respectively).

The average lifetime for furniture is significantly longer than for electronics. The lifetime of desks is roughly 16 years, 14 years for chairs, 13 years for sofas, 16 years for office cabinets, and 12 years for lab cabinets.

The lifetimes of lab equipment range greatly between machines, and also within a particular product type there is large variation in product life time. For instance the lifetime is 3 years for pipetters (SD of 2 years), 9 years for centrifuges (SD of 10 years), 12 years for mixers (SD of 8 years), 12 years for spectrometers (SD of 6 years), and 14 years for microscopes (SD of 10 years).

Table 23: The average lifetime (time period while registered as "active") of a sample of commonly purchased, and later deactivated, products.

Standard Product Name	General Category	Unit Count	Avg. Age (Years)	Std. Dev. Of Age (Years)
Laptop Computer	Electronics	9,537	4.9	2.6
Desktop Computer	Electronics	8,084	6.3	3.5
Server	Electronics	2,073	6.4	2.7
Printer	Electronics	1,306	10.1	3.9
Monitor	Electronics	1,180	9.0	4.2
Projector	Electronics	454	9.0	3.7
Freezer	Lab Equipment	448	5.6	5.9
Desk	Furniture	243	16.5	5.4
File Cabinets	Furniture	241	17.8	5.5
Table	Furniture	187	13.9	6.6
Centrifuge	Lab Equipment	173	9.0	9.7
Refrigerator (Lab)	Lab Equipment	160	6.1	6.9
Printer	Electronics	159	7.2	2.9
Pipetter	Lab Equipment	121	2.9	1.8
Facsimile Machine	Electronics	119	10.5	3.9
Exerciser (Fitness Gym Machines)	Other Equipment	114	9.9	5.0
Sofa	Furniture	85	13.3	6.3
Vehicle, Car	Automobile	62	11.1	5.3
Overhead Projector	Electronics	58	13.4	6.3

Of interest, a small number of products that are tagged by the property office have a short lifetime at MIT. Specifically, 11% of the products purchased in the data time period (constituting approximately 6% of the dollar value) were also deactivated by the university in that same time period. This is a relatively short turn-over period. This does show that the majority of items tagged by the property office does qualify as “stocks” (lifetime of 1 year or more). But, the small percentage of products that are high cost but leave campus within the year are not disposed of, but rather transferred out of MIT’s ownership.

Nevertheless, in FY16, 5,557 items were tagged (or activated) and almost all of these items did have multiple year lifespans at the University. For context, only 65 of the 5,557 items (purchased in FY16) were also deactivated in the same fiscal year. Most of these were laptop computers, and were transferred to a sponsor organization (such as a governmental office).

Outflows

Analysis of MIT's outflows was more straightforward than analysis of its inflows. MIT's waste is mostly handled by the Department of Facilities and the Environment, Health, and Safety Office. Within Facilities, Custodial Services aggregates municipal solid waste (MSW) from MIT's many buildings' bin and places them in dumpsters and larger bins at loading areas or loading docks. Facilities or MIT's waste hauler regularly collects waste from these loading areas and from outdoor bins into trucks. Truck-loads of material are brought to transfer stations or processors in the region. MIT's Grounds Services collects yard waste (grass clippings, woody materials, leaves) from campus for collection by a waste hauler.

More highly-regulated waste streams, such as hazardous chemical waste, medical waste, and radioactive waste are handled by lab managers, EHS, and the contracted waste processor (e.g., Clean Harbors). These categories of waste have special transport and safety requirements, and more data on the contents and building source is recorded per regulatory requirements.

It should be noted that the waste flows captured in this thesis mostly represent waste generated from MIT-owned buildings; waste generated in buildings leased by MIT are typically handled by other waste vendors, contracted by the building's owner.

Other than waste, MIT generates other material outflows, such as second-hand items that are sold, donated, or exchanged. Unfortunately, no institutional data exists on the quantity and types of these recoverable items that leave MIT to go on to have a second, useful life. Identified channels that assist with the dispersion of second-hand goods (leaving MIT) are the following:

- Book drives and book donation bins
- Used clothing collection bins
- Donation drives
- Choose to ReUse events
- MIT's Furniture Exchange
- MIT's ReUse Email list
- Trash2Treasure clean out events from residence halls
- Swapfest monthly events for the exchange of radio, electronic, and computer equipment

Quantity of Waste Generated by Category

In FY16, MIT generated about 5,376 metric tons of waste. This number excludes construction and demolition waste. MSW, including trash and single stream recycling, made up 88% of the total waste flows. The metric tons of waste by general category and specific material type are shown in Figure 23. Hazardous chemical waste was 8.3%, medical waste was 2.5%, and radioactive waste was 0.8% of the total.

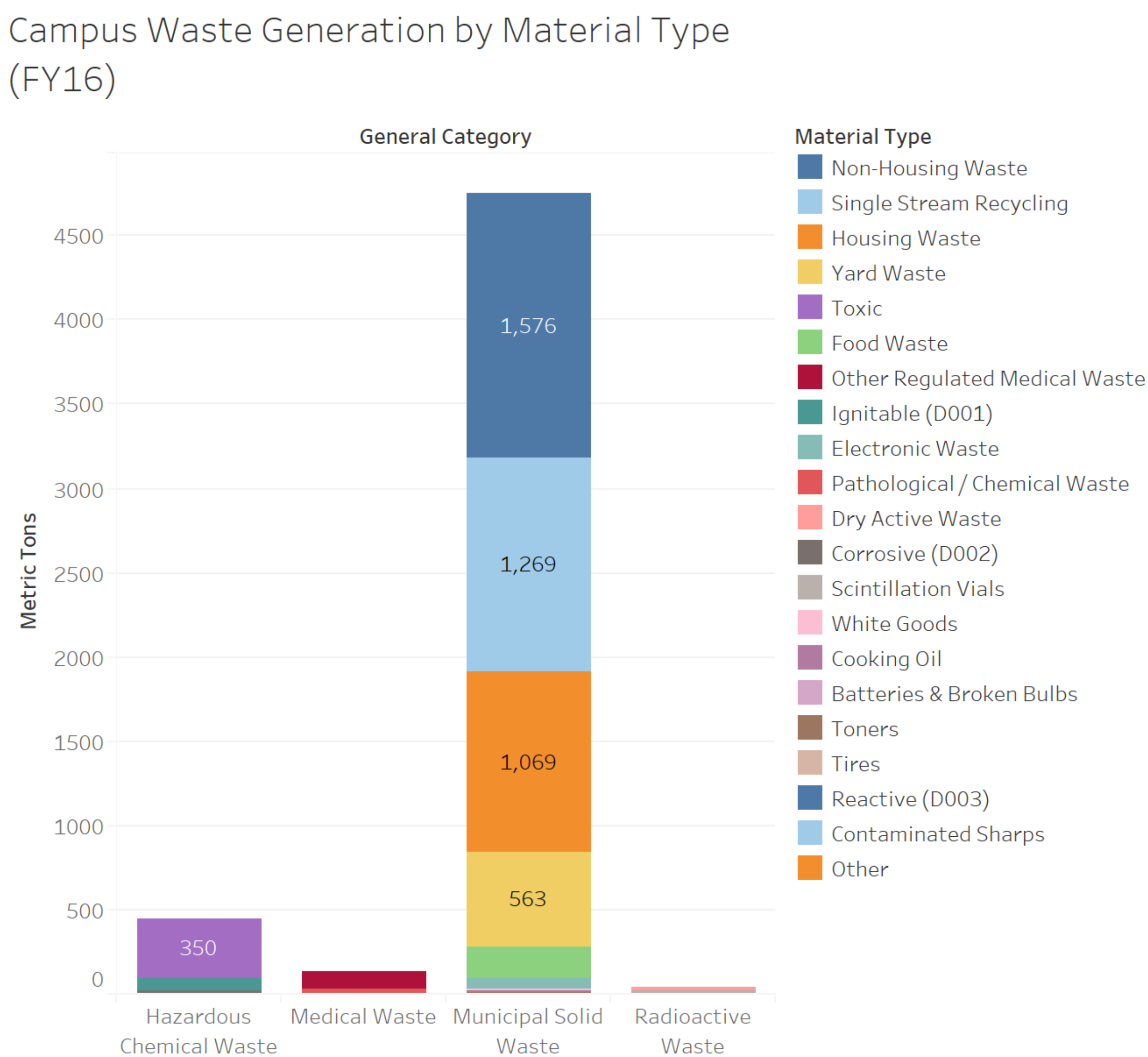


Figure 23: Campus waste generation in metric tons for FY16 shown by material type

Processing Methods/Destinations of Waste

As shown by Figure 24, MIT's trash is incinerated at waste to energy facilities. These facilities are typically within Massachusetts. MIT's single stream recycling is taken to a materials recovery facilities in Charlestown, MA, where it is sorted for recycling.

Yard waste is taken to several MA farm and open-air compositing facilities, and much is re-processed into nutrient-rich loam.

MIT collects food waste from about 20 locations (mostly at dining facilities) on campus. During the year 2016, food waste that was source segregated was composted. More recently, as of 2019, MIT began sending food waste to be slurried in Charlestown; then that slurry is trucked to a co-digestion plant that anaerobically digests both food waste and sewage. A small quantity of MIT's cooking oil is collected by a New-England based company for chemical upgrading to biodiesel for diesel engines or home heating furnaces.

Most of MIT's electronic waste (e-waste) is recycled or refurbished by regional facilities. Some additional regulated durable goods such as white goods (appliances), batteries, and used lightbulbs are also recycled at specialized facilities.

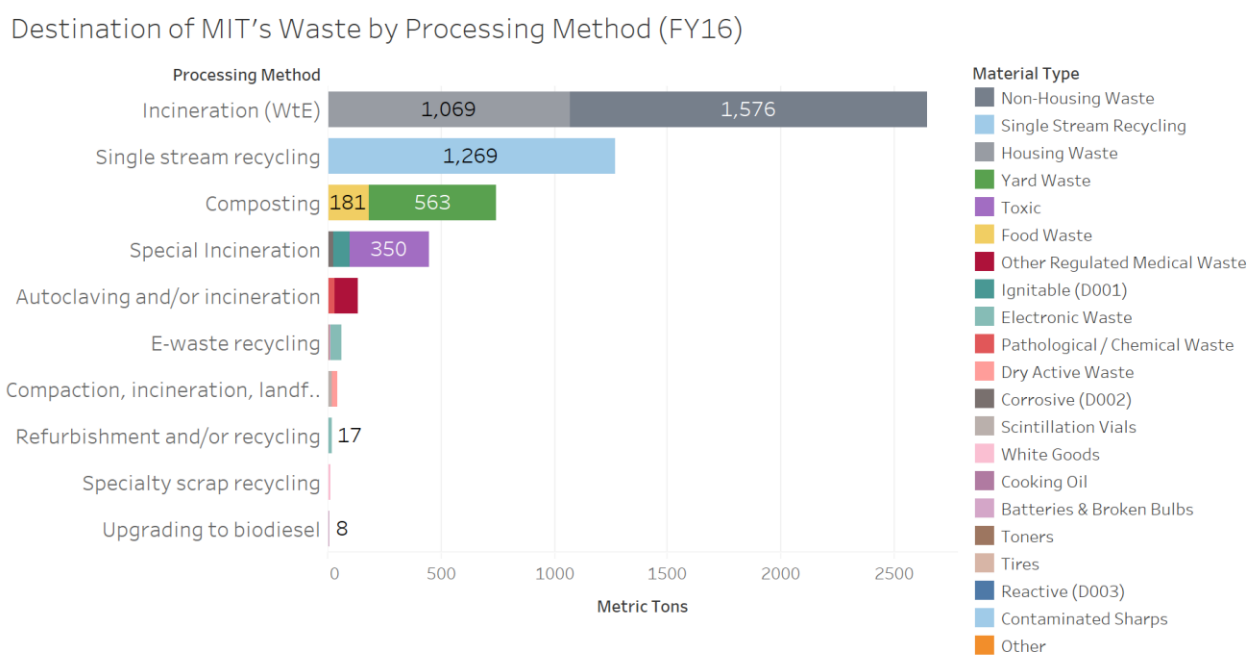


Figure 24: Waste or materials processing destination of MIT's outflows.

More Information about Hazardous and Medical Waste

Medical waste may be autoclaved or incinerated; autoclaving is a heat-based treatment that uses high-pressure steam to destroy microorganisms and spores. MIT categorizes medical waste into three subcategories, and the generation per subcategory for FY16 are as follows: pathological/chemical waste (25.9 MT), contaminated sharps (1.4 MT), and other regulated medical waste (106.8 MT).

At MIT, hazardous waste is typically consolidated in a drum or is lab-packed. Bottles of hazardous liquids are packed (by hazard class and compatibility) into drums with an absorbent material. The original label of the container must stay on, and a “packing list” is also created. Wastes with a high BTU value (that can serve as fuel) are poured-off into 55-gallon drums for incineration.

Much of MIT’s hazardous waste is disposed of at specialty incineration facilities that have hazardous waste combustors; waste is injected, spun, and burned, generating hazardous ash that must be landfilled. Much of the hazardous waste is sent to a facility in Colorado. These combustors usually operate at temperatures over 1,800 degrees Fahrenheit, and these processes and emissions are regulated under the Clean Air Act.

Figure 25: Photo of lab-packed bottles. Photo source: MIT EHS.

According to EHS, the breakdown of processing/disposal methods of hazardous waste is: 78.5% is incinerated, 8% is chemically landfilled, 5% is blended for fuels, 6.3% is processed for oil recovery, 0.3% is processed for metal recovery, 1.5% goes to waste water treatment, 0.2% goes to filtration, and 0.2% is processed with other methods.

Within the broad category of hazardous waste, five major hazardous waste categories exist: corrosive, ignitable, toxic, reactive, and other. These categories were identified with the help of EHS staff. MIT's generation volumes by major hazardous waste category are listed in Table 24.

Table 24: Generation of hazardous waste by major hazardous waste category.

Major Hazardous Waste Category	Generation FY16 (MT)
Corrosive (D002)	22.7
Ignitable (D001)	68.4
Toxic	349.8
Reactive (D003)	2.2
Other	0.6

When subdivided even further, the following specific material streams make up the top flows of hazardous waste by mass:

1. Flammable solvents consolidation (30.6 MT)
2. Lab-packed flammables for incineration (25.9 MT)
3. Waste debris with solvents (14.0 MT)
4. Garnet slurry (8.2 MT)
5. Non-hazardous salts, sugars, buffers (6.9 MT)
6. Lab-packed acid and acid compatibles for incineration (6.4 MT)
7. Lab-packed organics for incineration (6.4 MT)
8. Waste oil (5.6 MT)
9. Antifreeze (5.3 MT)
10. Flammable acidic waste (5.2 MT)

Of this list, the two streams that incur the highest waste management cost are the waste debris with solvents and the lab-packed flammables for incineration.

Temporal Variation of Municipal Solid Waste Generation

By working with MIT's Office of Sustainability and Department of Facilities, the author was able to obtain multiple years' worth of waste generation data. Annual generation between FY 2010-2018 is shown in Figure 26. There is a general downward trend in total waste generation, which is encouraging as an indicator of sustainability and waste reduction efforts. The proportion of single stream recycling to trash (housing and non-housing) has also increased, which is a measure of progress. Food waste collection, on the other hand appears to be decreasing over time, which likely reflects the fact that the scope of materials allowed in the food waste bin has become more restrictive over time. Originally, napkins, cardboard, and biodegradable PLA were allowed in the bin for composting; however, per the request of processors, food waste became the only permissible material for composting.

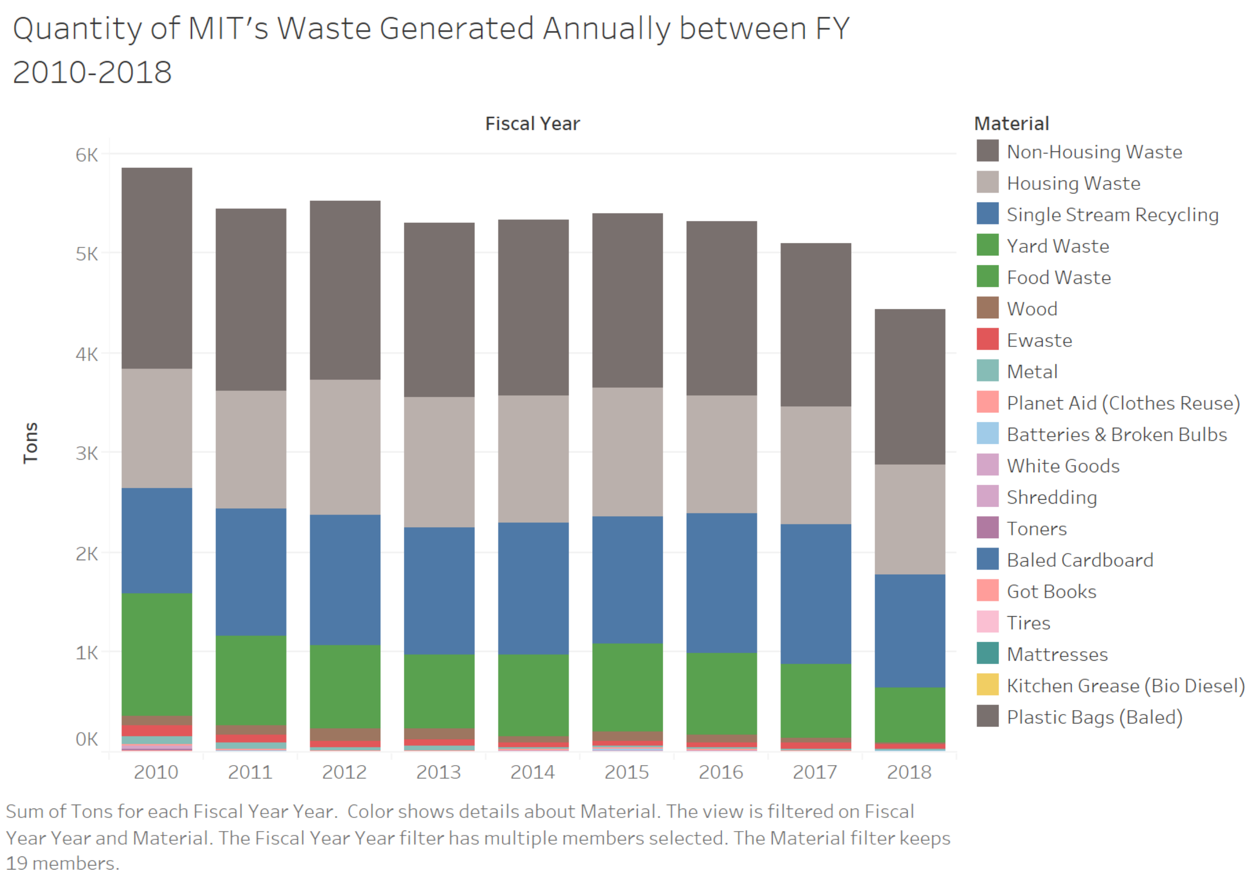
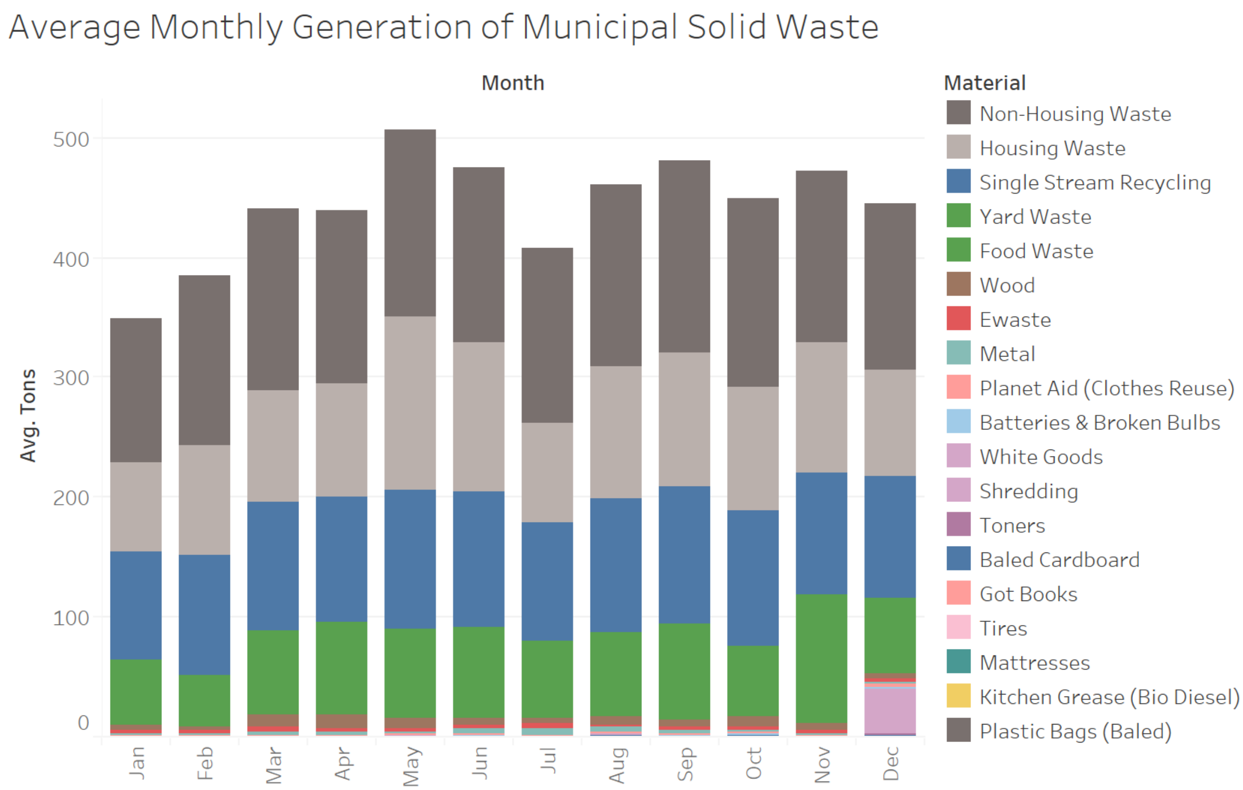


Figure 26: Quantity of municipal solid waste generated annually by MIT between FY 2010-2018.

In addition to comparing generation by year, a month to month comparison is shown in Figure 27. Generation does indeed vary by month. These averages are based on nine years of data (2010-2018). Average generation (for the aggregate of all MSW categories) is lowest during the months of January, February, and July, and are highest during the months of May and June. Waste generation in January is likely particularly low due to the absence of many undergraduate and graduate students, who travel or return to their family homes for that month, which is MIT's Independent Activities Period. Waste generation is probably particularly high in the month of May due to move-outs from residential dorms and office clean outs that typically go along with "spring cleaning."



Average of Tons for each Month. Color shows details about Material. The data is filtered on Fiscal Year Year, which has multiple members selected. The view is filtered on Material, which keeps 19 members.

Figure 27: Average generation of MIT's MSW by month.

Composition of Trash and Recycling (based on Waste audits)

As described in Chapter 2, the composition of MIT's trash and recycling streams were determined empirically by the author with waste audits. Those average compositions are listed again, below, in Table 25.

Table 25: The composition (by weight) of the waste in MIT's single stream recycling bins, based on the campus waste audits. Green = compostable, blue = recyclable in single stream recycling, and red = disposable or recyclable using specialty recycling services. (This is the same as Table 10, duplicated here for convenience).

WASTE CATEGORY	Average Composition of Campus TRASH	Average Composition of Campus RECYCLING
Food waste	29.2%	3.9%
Yard waste	0.3%	0.0%
Soiled paper products	20.2%	6.9%
PLA bioplastic	4.5%	2.5%
High grade copy paper	1.9%	5.1%
Mixed paper	4.6%	9.7%
Boxboard	2.3%	1.9%
Paper cartons (e.g. Tetra PAK)	0.4%	0.0%
Corrugated cardboard	2.3%	22.4%
PET Containers (#1)	2.3%	20.0%
HDPE Containers (#2)	1.4%	5.0%
Misc. recyclable plastic containers (#3-7)	6.0%	5.6%
Aluminum	1.2%	4.4%
Steel	0.5%	0.4%
Glass containers	4.2%	3.0%
Film plastic	2.3%	4.6%
Multilayer packaging	0.5%	0.3%
Polystyrene foam (i.e., Styrofoam)	0.0%	3.3%
Batteries	0.5%	0.0%
Small electronics	2.2%	0.8%
Other / miscellaneous waste	13.0%	0.0%

Revised Waste Quantities (based on Waste Audits)

The averages from above were used in combination with the total masses of trash and recycling to estimate mass flows of each of those 21 material categories. The full set of waste flows by highly specific categories are presented in Table 26. As shown by the table (which has larger mass flows highlighted with darker blues), the largest flows are believed to be:

(1) Food waste
(2) Soiled paper
(3) Yard waste
(4) Cardboard
(5) Toxic hazardous waste

The full waste management "story" is displayed in Figure 28, which contains a Sankey diagram showing general waste categories, specific waste flow categories, and the processing method.

Table 26: Waste flows (in MT) by highly-specific categories. These figures are based on a combination of institute data and empirical waste audits.

Specific Waste Flows (MT)
Based on Waste Audits

General Cat..	Material Type	
MSW	Aluminum	86.5
	Batteries	1.1
	Batteries & Broken Bulbs	8.4
	Boxboard	85.9
	Cardboard	372.1
	Cooking Oil	8.5
	Ewaste	61.0
	Film plastic	180.1
	Food Waste	970.0
	Glass bottles	206.4
	HDPE containers (#2)	101.7
	High grade office paper	123.6
	Misc. plastics (#3-7)	224.1
	Mixed paper	261.8
	Multilayer Packaging	61.5
	Other Waste	337.8
	PET bottles (#1)	317.8
	PLA "plastic"	79.3
	Small electronics	11.6
	Soiled paper	577.7
	Steel	23.4
	Styrofoam	55.4
	Tetrapack	10.8
	Tires	2.7
	Toners	6.3
	White Goods	9.4
	Yard Waste	569.1
Bulk Materials	Metal	13.2
	Wood	77.5
Hazardous Chemical Waste	Corrosive (D002)	22.7
	Ignitable (D001)	68.4
	Other	0.6
	Reactive (D003)	2.2
	Toxic	349.8
Medical Waste	Contaminated Sharps	1.4
	Other Regulated Medical ..	106.8
	Pathological / Chemical W..	25.9

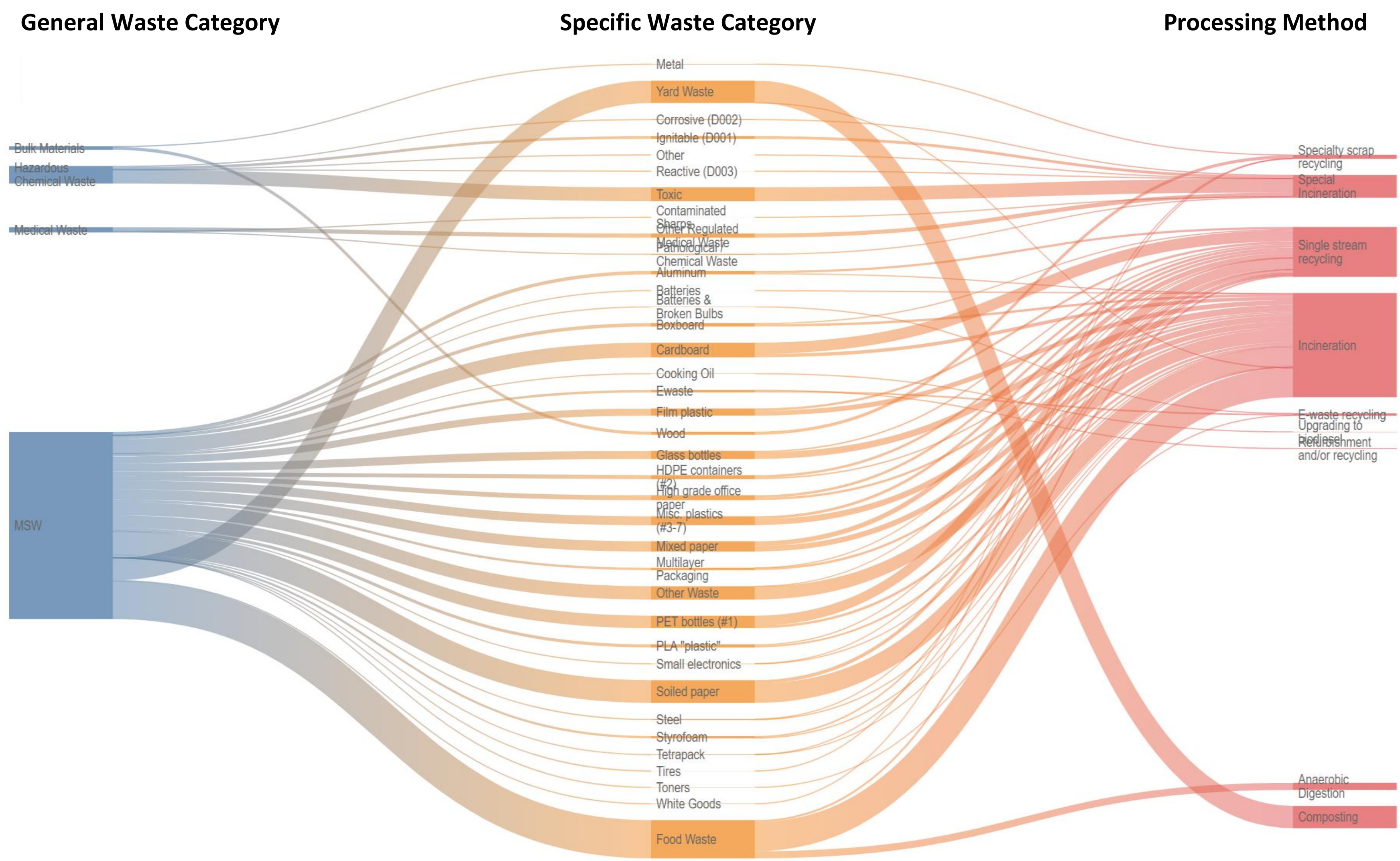


Figure 28: A Sankey diagram showing general waste categories, specific waste flow categories, and the processing method.

Chapter 5: Estimating Greenhouse Gas Emissions from Inflows and Outflows

Chapter 5 Abstract

This chapter lays out the methods and results of estimating greenhouse gas emissions for purchases and waste management from MIT material streams. To estimate the embodied GHG emissions from purchases, spend data was used with an economic input-output life cycle assessment (EIO-LCA). The product categories with the largest embodied emissions were found to be laboratory supplies, chemicals/gases, office furniture, and electronics. The total embodied greenhouse gas emissions of material goods purchased in FY2016 was found to be roughly 78,800 metric tons of CO_2-eq. This is significant compared to Scope 1 and 2 emissions. Emissions from waste management were estimated using waste generation figures and EPA's WARM model; the results indicate that the greenhouse gas impact from waste is much smaller than that from procurement. The method used in this analysis may serve as a starting place for other universities to follow in estimating the materials portion of Scope 3 emissions. The results serve to provide a point of comparison, and answer the question of how important this accounting is by magnitude. Lastly, the chapter provides recommendations for how others might do further analysis of greenhouse gas emissions and other environmental metrics.

Introduction

Beyond quantifying the material commodities entering and leaving the university, it is valuable to quantify the environmental impact of those flows and identify those that are largest. One relevant environmental impact of product/ material flows is the associated global warming impact, or carbon footprint. For waste, this impact is the greenhouse gas (GHG) emissions associated with waste management of those flows. For purchases, this is the embodied greenhouse gas emissions of those products or materials. Emissions from both these categories fall into Scope 3 greenhouse gas accounting. Universities often report their Scope 1 and Scope 2 emissions, but do not report Scope 3 emissions, due to lack of information and the complexity of accounting of upstream and downstream emissions.

Because of the diversity and quantity of individual products/materials consumed by the university in a year's time, it is clearly not feasible to conduct an end-to-end life cycle analysis for every single product. Instead, this analysis separately assesses GHG emissions from purchases purchasing and from waste management using modifications of pre-existing tools. The tools used for this analysis were selected based on the following criteria:

(1) Allowing for the estimation of GHG emissions for a broad set of material/product categories, including those consumed by a university campus
(2) Open-source or available for a small cost
(3) Relatively up-to-date platform and/or data
(4) Designed and maintained by a reputable academic/scientific institution

(5) Recommended by experts in the field that were consulted

Estimating the Embodied Greenhouse Gas Emissions from Purchases

To estimate the embodied GHG emissions from purchases, a form of economic input-output life cycle assessment (EIO-LCA) was used. EIO-LCA is a method that estimates the materials and energy resources required for, and the environmental emissions resulting from, economic activities. These economic activities are categorized at the industry level. The model pairs nation economic input-output models with publicly-available resources use and emissions data to provide environmental assessments. EIO-LCA tools, which use aggregated industry-wide data, differ significantly from product-based life cycle tools (e.g., Ecoinvent or GaBi), which require specific product information.

Method for estimating embodied greenhouse gas emissions from purchased material goods

The specific EIO-LCA tool used in this project was USEEIO, an environmentally-extended input-output model of the United States that is publically available. USEEIO is suited for performing streamlined life cycle assessment of goods and services and uses relatively current data, with most environmental impact data representing 2013 and the economic data representing 2007 (Yang et al., 2017). As stated by Yang, "USEEIO melds data on economic transactions between 389 industry sectors with environmental data for these sectors covering…emissions of greenhouse gases… to build a life cycle model of 385 US goods and services.

Some modifications were made to the USEEIO model to tailor the methods to best reflect the nature of data and conditions surrounding the particular parameters in this study. Generally, the fundamental process involved matching purchase categories with relevant emissions factors. Outlined below are the specific steps used to estimate Global Warming Potential (or GWP) using data on expenditures of material goods.

1. Obtain all of the university's purchase records for Fiscal Year 2016.
2. Categorize the purchases into three major categories:
   (1) Material Goods, within the Scope of Study
   (2) Material Goods, outside of the Scope of Study
   (3) Services, outside the Scope of Study
3. Select all Material Goods within the Scope of Study and segment them into product categories. Match each university product category with one of the 385 USEEIO codes. USEEIO codes are relatively similar to specificity of NAICS (North American Industry Classification System) codes. USEEIO codes are all US specific (they assume manufacture takes place in the US).

4. The goal was to prepare the data to be used with the USEEIO model, which is an input-output life cycle assessment tool that estimates embodied GHG emissions of various industries. Since the USEEIO model is based on 2007 dollars, convert all 2016 dollars to 2007 dollars using the Bureau of Labor Statistics' Consumer Price Index Inflation/Deflation calculator, which can be found at https://www.bls.gov/data/inflation_calculator.htm.

5. Use OpenLCA software to run the USEEIO model to estimate the Global Warming Potential (in MT of CO2-eq) for each MIT product category (e.g., laboratory equipment). Call these outputs the original USEEIO GWPs.

6. It must be acknowledged that USEEIO-calculated industry emissions are usually at the point of manufacturer (e.g., “Plastics; at manufacturer”), rather than at the point of sale. However, the dollar values available to the author are based on purchase records, and therefore represent the amount spent on purchased goods; these prices paid include distribution costs, shipping costs, and retailer markup. Therefore, an adjustment needs to be made to match the boundaries. USEEIO only has producer prices, and does not have purchaser prices. Therefore, it was necessary to calculate adjustment factors by using another economic input-output life cycle assessment tool, EIO-LCA, developed by Carnegie Mellon (Gan & Matthews, 2018).
    a. For a given material category, find its closest match in EIO-LCA.
    b. Then, use the 2002 US National model to find the GWP per 1 million dollars. The exact dollar amount is arbitrary, since it is used to calculate a ratio in (a) Producer Price Model and (b) the Purchaser Price Model.
    c. Find the ratio of GWP from Purchaser Price divided by the GWP from the Producer Price. The ratios were typically <1, with an average of 0.9. This ratio, associated with each category, served as the multiplication factor to adjust for purchaser price. This adjustment method was used for all codes used in the analysis, except for “Limited-service restaurants,” which was matched to spend on purchase areas like catering and dining. For any category matched as a limited-service restaurant, the purchaser-producer adjustment ratio was kept as a factor of 1, because there is no “at manufacture” stage. A sample of the data used for calculations is shown in Table 27.

Table 27: Sample of data and calculations used to estimate GHG emissions from purchases using a modified version of the USEEIO model.

MIT purchase category	Relevant USEEIO code	Associated EIOLCA (CMU) code	EIOLCA US 2002 PRODUCER GHG per $1M (MT CO2-eq)	EIOLCA US 2002 PURCHASER GHG per $1M (MT CO2-eq)	Adjustment ratio for purchaser price
Laboratory Supplies	Plastics; at manufacturer - US	32619A: Other plastics proc	904	748	0.827
HW Purchase / Maintenance	Computers; at manufacturer - US	334111: Electronic Comput	284	276	0.972
Laboratory Equipment	Analytical laboratory instruments; at n	334516: Analytical laborato	335	337	1.006
Chemicals, Reagents, & Gase	Chemicals (except basic chemicals, agr	325188: All Other Basic Inoi	2180	2060	0.945
Office Furniture	Institutional furniture; at manufacture	337127: Institutional Furnit	647	613	0.947
Catering	Limited-service restaurants - US		KEEP RATIO 1		1.000
Drugs & Pharmaceuticals	Pharmaceutical products (pills, powde	325412: Pharmaceutical Pr	336	304	0.905
Meals & Entertainment	Limited-service restaurants - US		KEEP RATIO 1		1.000
Electrical Components	Electronic capacitors, resistors, coils, t	334417: Electronic Connect	586	582	0.993
Audio Visual Supplies & Serv	Audio and video equipment; at manufa	334300: Audio and video ec	549	446	0.812
Office Supplies	Office supplies (not paper); at manufac	339940: Office Supplies (ex	535	391	0.731
General Industrial Supplies	Printed circuit and electronic assembly	334418: Printed circuit asse	400	390	0.975
Research Specimens	Animal farms and aquaculture ponds (	112A00: Animal production	3620	3440	0.950

7. The assumption of manufacture origin country/ region can significantly alter the global warming potential of manufactured goods, due to the differing carbon intensities of regional electricity grids. The USEEIO model calculates emissions based on the assumption that all goods are manufactured in the US. However, it should be acknowledged that many products commonly purchased by MIT are manufactured in other countries. In order to make best-estimates on region of origin for each MIT product category, export and import data by product type were analyzed using an existing online tool called the Observatory of Economic Complexity (developed by the MIT media lab). The tool can be accessed via atlas.media.mit.edu. The product categories on this tool align with the Standard International Trade Classification system.

8. Country-specific electricity emission factors for all countries identified above were researched. Emission factors from *Ecometrica* were used (Brander et al., 2011). A GWP adjustment factor was obtained by dividing the country's emission factor by the US-specific emission factor. For instance, since China's emission factor was found to be 0.973 kg CO_2 per kWh, and the US emission factor was 0.547 kg CO_2 per kWh, the emission adjustment factor for a product made in China was 0.973/0.547 = 1.78. This adjustment assumes that all of the energy used to manufacture these products is electricity-based energy. Further work could attempt to segregate products that use non-electricity energy sources, and adjust emission factors accordingly

9. To obtain the adjusted GWP contribution for each product category, use the following equation, developed by the author:

$$\boldsymbol{GWP\ for\ category\ c = S_c \times d_{2007} \times GHG_c \times p_c \times e_c \times 0.001}$$
$$\boldsymbol{TOTAL\ GWP = \sum_c S_c \times d_{2007} \times GHG_c \times p_c \times e_c \times 0.001}$$

Where:

- $TOTAL\ GWP$ = Global warming potential for the sum of all product categories (Metric tons CO_2-eq)
- S_c = 2016 spend on product category c ($)
- d_{2007} = deflation factor to convert $2016 to $2007 (dimension-less) = 0.8543
- GHG_c = Greenhouse gas emission factor for product category c obtained from USEEIO model (kg CO2-eq / $2007)
- p_c = adjustment factor to account for the difference in purchaser price vs manufacture price for category c (dimension-less)
- e_c = adjustment factor to account for the carbon intensity of the electricity in the country of origin for product category c (dimension-less)

Results

The global warming potentials by purchase categories are shown in Figure 29; only the top contributing categories are shown in this graph. The product categories that contribute most to the university's GWP of material purchasing are: (1) laboratory supplies, (2) chemicals, reagents, and gases, (3) office furniture, (4) IT hardware, and (5) laboratory equipment.

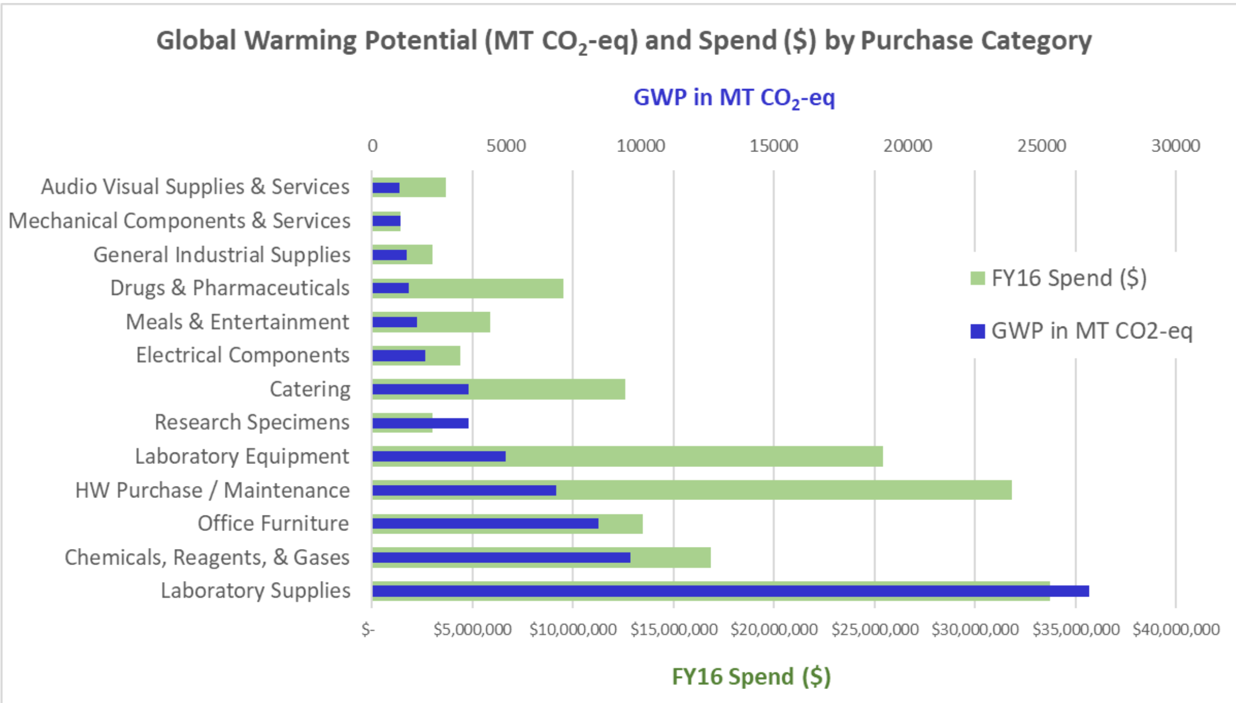


Figure 29: The Global Warming Potential (in MT CO2-eq) and FY16 spend by purchase category for the most carbon-intensive product categories. GWP is shown in dark blue, and spend in dollar is shown in green.

When summed, the total GHG emission from purchased goods for FY16 is 78,806 MT CO_2-eq. When compared to MIT's Scope 1 and Scope 2 emissions, this proves to be a substantial proportion of total emissions. As shown in Figure 30, GHG emissions from purchased goods are estimated to represent 28% of total emissions. If the full span of purchases – including services – were evaluated for their GWP contribution, Scope 3 emissions would likely be much larger.

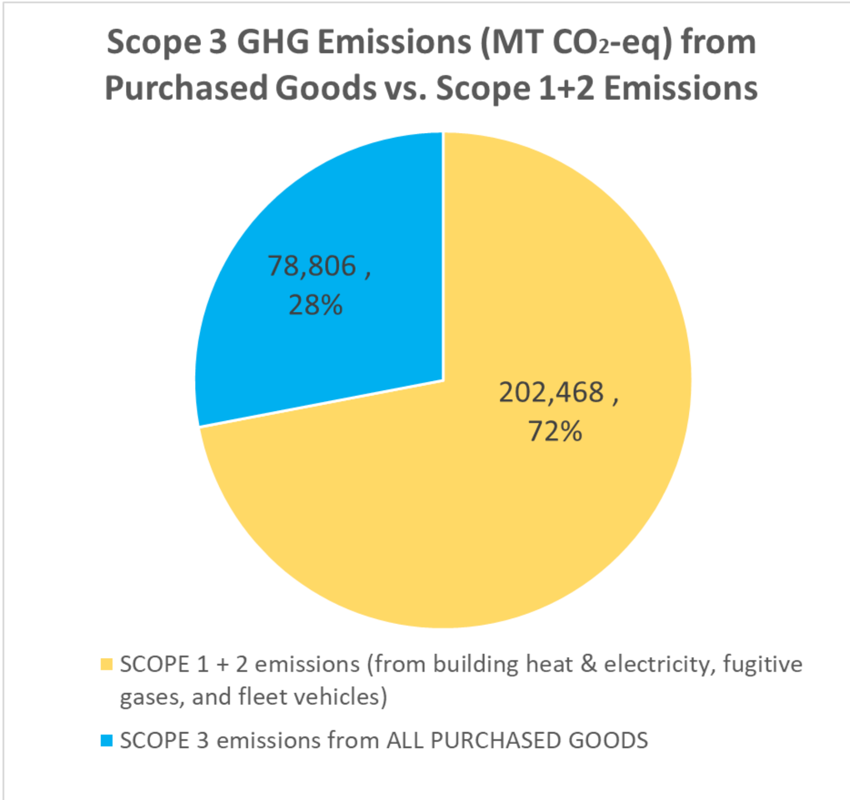


Figure 30: Comparison of GHG emissions from purchased material goods (part of Scope 3) to Scope 1 and 2 emissions.

To help validate the accuracy of the GWP estimate calculated above, a lower-bound reference value of GWP was computed. One of the industry codes in USEEIO is "Colleges, universities, junior colleges, and professional schools – US." Emissions were estimated assuming that the total expenditure on material goods fell under this general college/university category, and no other model modifications were used. This resulted in the value of 53,175 MT CO_2-eq. The fact that this second estimate is smaller, but on the same order of magnitude as the above estimate of 78,806 MT CO_2-eq, strengthens the legitimacy of the original estimate. It should be expected for the second estimate to be smaller, because it represents a general higher-education industry that would typically use fewer energy-intense materials consumed by a technical engineering university, like MIT.

Problems/Limitations

Given limitations on time and data-availability, and given the complexity of the task, this project's estimate of GWP from material goods purchasing is believed to be reasonable. However, there are potential sources of error and opportunities for improving emission estimates. Potentially, the largest source of error may come from situations where purchase categories did not match well with USEEIO categories. The purchase categories specified in the MIT data were often significantly more specific than the industry codes, which left the author to make relatively subjective matches based on best approximation.

The following are other potential sources of error that might have made the GHG estimates larger or smaller than their true value:

- An inaccurate ratio of manufacturer price to purchaser price
- Inaccurate adjustments based on country of origin and carbon intensity of the electricity grid
- Inherent heterogeneity of the specific purchases that is not captured by the general product category or industry category

Estimating the Greenhouse Gas Emissions from Waste Flows

Method for Estimating Greenhouse Gas Emissions from Waste Flows

To estimate the GHG emissions from waste management, the US Environmental Protection Agency's WARM model (or the EPA Waste Reduction Model) was used. In necessary cases, when a material category or processing method was represented in WARM, life cycle emission values from published studies were used. According to the EPA, "WARM calculates and totals [greenhouse gas emissions and emission reductions] from baseline and alternative waste management practices—source reduction, recycling, anaerobic digestion, combustion, composting and landfilling" (U.S. Environmental Protection Agency, 2019).

WARM uses global warming potential values from IPCC Fourth Assessment AR4 (2007), which is the generally-accepted standard. WARM can be used with Microsoft Excel and requires specifying the waste material and the processing type / disposal type. In implementing WARM, default transportation distances were used. The author used WARM to calculate GWPs for all flows where there was a close or exact match. For cases where a better match could be found, an external emissions factor was used. Published estimates of GWP for a few waste categories and processes could not be found, and obtaining an estimate would have required conducting a life cycle analysis. In these cases, the waste stream was excluded from the emissions analysis. This was the case for two relatively small streams: E-waste recycling of "Batteries and Broken Bulbs" and the conversion of used cooking oil to biodiesel.

Results

The estimates of GWP by waste stream are presented in Table 28. “Negative” GWPs with blue bars represent avoided emissions, and “positive” GWPs with red bars represent generated emissions. The net emissions from the management of all waste streams is an avoided 2,898 MT of CO_2-eq. The waste streams with the largest GHG contribution were found to be film plastic, miscellaneous plastics (#3-7), and Styrofoam, all of which are mostly incinerated after leaving MIT. The waste streams that appear to have large avoided emissions are cardboard, aluminum, and mixed paper, all of which are assumed to be recycled. This is a reasonable assumption, given that the year of study was 2016; this preceded most of the problems with finding outlets for certain recycling streams due to the National Sword policy of China.

Negative emissions do not reflect captured emissions – it is only showing avoided emissions in a scenario where there is an assumption (made in WARM) that the status-quo uses 100% virgin material. The emission assumptions contained in WARM reflect an extreme scenario that is not representative of the real world, and probably underestimate true environmental impact (or overestimate environmental benefit).

Table 28: The Global Warming Potential of MIT's waste management listed by waste stream.

Global Warming Impact for management of MSW generated by MIT during FY2016.		
Waste Stream	**Global Warming Potential (MT CO2-eq) per WARM model**	**US Tons of Waste Generated**
Aluminum	-557.80	95.40
Batteries	-0.08	1.18
Boxboard	-130.28	94.71
Cardboard	-1027.55	410.21
Ewaste	-48.13	19.22
Film plastic	245.55	198.58
Food Waste	-135.46	1069.19
Glass bottles	-6.51	227.53
HDPE containers (#2)	-8.91	112.05
High grade office paper	-236.17	136.26
Misc. plastics (#3-7)	125.77	247.02
Mixed paper	-559.23	288.55
Multilayer Packaging	-4.44	67.80
Other Waste	-24.40	372.37
PET bottles (#1)	-226.55	350.30
PLA "plastic"	-5.73	87.45
Small electronics	-0.84	12.79
Soiled paper	-41.73	636.81
Steel	-42.05	25.83
Styrofoam	97.71	61.09
Tetrapack	-6.92	11.90
Tires	-1.11	2.96
Wood	-211.12	85.45
Yard Waste	-91.98	627.30
Grand Total	**-2897.96**	**5241.94**

The same emission values are presented in a different way in Figure 31, but are presented by waste processing type (as opposed to waste material). This figure highlights the fact that the streams with the largest mass of material are not always the ones with the largest (by magnitude) GWP. Most of emissions generated come from specialty incineration of hazardous waste and incineration of MSW. Relatively large emission reductions come from single stream recycling.

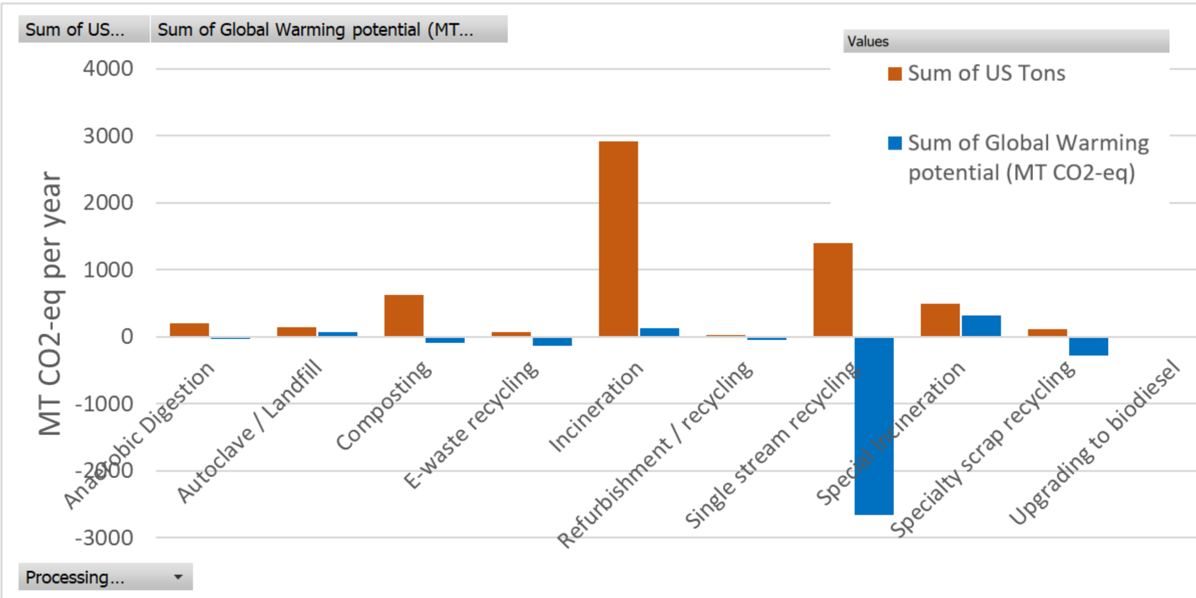


Figure 31: The Global Warming Potential of MIT's waste management, presented by waste processing type. The bars in orange represent the tons of waste, and the bars in blue represent the MT of CO_2-eq.

Discussion about Global Warming Impacts

One important take-away from the above analyses is that the global warming potential from purchasing is far larger than emissions from waste management. Even if the net emissions from waste management resulted in being positive, instead of negative, they would likely be much smaller in magnitude than those from purchasing. This result has an important implications: it means that if MIT is prioritizing methods for reducing its GHG emissions, it should focus more on reducing its purchasing (especially of carbon-intensive materials) than it should focus on directly reducing waste management emissions. This is also a wise choice because reducing the quantity of purchased goods will have the secondary impact of reducing waste generation. However, a university may have other motivating reasons to spend time and money on reducing waste – for instance, waste streams can have problematic impacts other than global warming, such as toxicity or negative health consequences for humans.

Chapter 6: Organizational and Behavioral Factors Impacting Purchasing

Chapter 6 Abstract

This chapter reports the findings from sixteen in-person interviews conducted with MIT community members that make purchases. Each interview went into depth and the findings provide valuable insight about the cultural context of purchasing at MIT. The interviews were highly informative for understanding behavioral drivers of purchasing, level of interest in and ability to make sustainable purchasing and disposal choices, and receptiveness to potential policies and programs. Among other findings, the interviews revealed that purchasers currently have a high level of individual agency and freedom. Purchasers also reported that they would like easily accessible information and guidelines for how to purchase sustainably, as well as formalized incentives for buying more sustainably and conserving materials.

Interview Methods

To better understand how purchasing works, in practice, at MIT, the author interviewed a diversity of MIT community members that regularly make purchases of material goods. The intention was to learn about the personal experience of people who make purchases. These human perspectives could enhance understanding of the system, beyond the objective purchase record data. These subjective responses could add information important to adding depth and revealing unexpected elements about the purchasing process and purchasing behavior. The author conducted in-person, semi-structured interviews that lasted between 20 minutes to 1 hour. Before conducting the interviews, the author underwent human-subjects research training and obtained approval for the study from MIT's Committee on the Use of Humans as Experimental Subjects (COUHES). The author followed the interview guide provided in the Appendix.

Sixteen MIT community members (n = 16) were interviewed in this project. The number of interviews conducted was not sufficient for conducting statistical analyses on purchasing behavior or to definitively characterize purchasing habits across the university. However, it was sufficient to gather in-depth understanding of the cultural, organizational, and behavioral factors influencing purchasing at MIT.

The interviewed individuals that self-identified as people that make purchases with MIT funds to be used by part of the MIT community. In each interview, I confirmed that each interviewee makes some material goods purchases for the University. Specifically, the participants ranged in age from 23 to 65 years old. Ten were woman, and six were men. Their time working/studying at MIT ranged from 1 to 32 years. The individuals' positions at the university were the following: six administrative assistants (of various levels), three scientific/technology laboratory managers, two academic administrators, one graduate student, one safety engineer, one stewardship assistant, one instructor/ associate director of a research center, and one program coordinator. Collectively, the participants reported that they buy a range of products including: food (catering, coffee), computers and electronic peripherals, office supplies (printer toner, notebooks, folders, & pens), printer paper, tissues, bottled water, lab equipment (microscopes, ovens), lab supplies (petri dishes, pipettes, gloves), chemicals, gas cylinders, personal protective equipment, audio-visual equipment (cameras, lenses), clothing, cleaning supplies, disposable cutlery, and furniture.

Interview Findings

Logistics of purchasing

When asked about why they buy the kinds of products they buy, multiple participants reported that they buy repeatedly from a vendor they like. For some, an important quality in vendors is good customer service. Others selected vendors and purchasing methods that were "easy," and multiple individuals said they favored using "MIT preferred vendors." Another convenience factor mentioned by one purchaser was that she will do "whatever allows me to put all purchases into one order." Many also reported that the reason they will make a purchase is to simply replace supplies that run out, and they buy an identical product as before. One individual stated, "We order the same thing we had before, as long as it is not giving us any trouble." This sentiment was expressed by other interviewees, who said:

- *"Some projects are repeated multiple times, so I buy the same product each time, and replace them when they run out."*
- *"If I have used something before and like it, I will use the vendor again and buy from them."*
- *"I look for MIT-preferred products. I tend to just replace the same items we had before."*

The reported frequency of purchasing ranged from twice a day to once a month. The participants said that the following events determine when they buy: supplies running out, something breaking, someone requesting something they need. For the most part, the timing of purchasing was not driven by the fiscal year.

When asked about the purchasing platform the participants most commonly used, they said they mostly use the online catalog (where they buy from preferred vendors); outside of that, the most common purchases are credit card purchases of catering and Amazon. Almost all purchases are made online. One person even admitted, "I buy it all online and use a p-card, because I hate talking to people and getting quotes."

Fifteen of the sixteen participants said they purchase material goods for others, and seven said that sometimes others (superiors, colleagues, etc.) buy products for them. These purchasers are only sometimes the end-users of the products they buy. This has implications for disposal, which discussed later in the chapter.

Major Considerations

To identify the purchasers' primary considerations influencing purchase decisions, the purchasers were asked to explain the major factors they consider when selecting items to purchase. The most commonly mentioned factor was product quality, which was referenced by ten of the participants, and was frequently described as the most important consideration. The next-most reported considerations were affordability/value (n = 6), delivery time (n=5), and suitability of the product to fit the required purpose or specifications (n=5). The views on the importance of cost varied significantly. For instance, one participant explained that "Budget is a big part of it, because we are so lean." The moderate view was also represented when a participant explained that "Cost is important to me, but I don't sacrifice quality or consistency for cost." This strongly contrasted with another participant that said, "Price is not really a factor, because we can usually find the money for something or request extra money – for instance, we don't compare the prices of different caterers." Additional comments that demonstrate the prevalence of the above factors are listed here:

- *"Quality is number 1. Shipping time is also important."*
- *"Quality and cost are the most important. And time is so valuable."*
- *"The most important thing is that the product suits the task at hand. If the product will be used for a task repetitively, the manufacturing quality is important - durability."*
- *"First priority is that it fits the purpose. It needs to do what's needed. The two next important features are that it is either durable (because it will get used by many students), or, it should be reasonably priced."*
- *"First off, the item needs to serve its purpose. I am also cost conscious, so I look for lower prices."*
- *"Most important is that it fits the need/want of the requester. Quality is next important - for instance, I look for paper that it is good quality. Customer service is probably third."*
- *"Value (decent quality for a good price) is most important."*
- *"A lot of what we buy is replacement, so we will go with the same thing we have bought before. The biggest factor is that it fits our technical and research needs."*
- *"The most important thing is quality. I want the product to last."*

Other factors mentioned by multiple participants included convenience (n=4), vendor reliability or trust (n=3), habit (n=3), durability (n=3), sustainability (n=2), and the vendor being an MIT-preferred vendor (n=2). Regarding vendor selection, one purchaser expressed her strong preference for preferred vendors saying, "It has to be something really important or weird for me to have to go outside of [the online catalog]." Another participant liked preferred vendors because she considered them pre-vetted; she said, "I tend to go with preferred vendors as much as possible. I trust [MIT has] done the job upfront, so I don't have to do research on vendors."

Customer service, word-of-mouth recommendations, and the ergonomics of design were each mentioned by only one participant. Purchasers for laboratories had some concerns specific to their field. For instance, one lab manager mentioned that "students often look at purities of products as part of their decision" when they make purchase requests. Another relevant consideration for purchasers of large equipment was shipping logistics; a lab manager explained that "For big equipment, I look at who is going to pay for shipment, and who is going to be liable for the product from the moment it gets to the loading dock to when it gets into the lab. Especially for big equipment, the logistics and shipment need to be worked out in advance to make sure that it gets into the lab."

As expected, most of the factors that were mentioned related to practical work issues. However, there was only one person that brought anything related to the pleasure products can give users; she said, "It's important that the person I am buying the product for likes it – something as simple as a brightly colored pad of paper can make someone happy."

Freedom

The participants were also asked how much freedom they have in making purchase decisions. Generally, the participants reported that they have a high level of freedom in cases when they are buying from a preferred vendor. Some responses included comments such as, "I have near total latitude," and there is "Complete freedom; I can select what I need or want." One individual said, "Sometimes I feel like we have too much flexibility… I have never been called out for spending too much money." Another comment was "In some sense, no one cares what I do, as long as they get what they want individually." Others had a more nuanced view, for instance, stating, "There is an established process, but I have the freedom to use my judgement."

Personal vs. University Purchases

In response to being asked how purchasing for MIT was similar or different from personal purchases, the participants said that their priorities were somewhat similar in both situations. Some reported that they do more online purchasing for MIT than they do at home. There were, however, mixed views on how price impacted work-related versus personal purchase decisions. One individual said that in contrast to her purchasing behavior at MIT, "At home, if I can do without it, I won't buy it." Another person said, "As a personal consumer, I look for sales, which isn't always practical for MIT purchases." That is, prices for products from MIT preferred vendors are pre-negotiated, and are usually not subject to discounts. A third view voiced was, "I treat money at both work and home carefully. I am perhaps even more conscious here at MIT, because it is not my money." These responses show that there is heterogeneity in the level of concern over price for personal versus university purchases.

Relating Purchasing to Disposal

About midway through each interview, the participant was asked about how disposal of products factors in to the purchasing process. Of the sixteen interviewees, eleven said that they are, at least sometimes, responsible for making the disposal decisions for the materials they buy at MIT. They mentioned items such as tagged equipment, chemicals, shipping packing, printer cartridges, and batteries as products that they are responsible for disposing. For instance, one employee said, "I oversee disposal of batteries. We have a battery recycling area near the stockroom." Another participant stated, "I am the one that deals with disposal for equipment. I make the request for pickup. A lot of it is tagged property, so I make a request for deactivation through the Property Office." One staff member added, "People ask me what to do with items they don't need… there is a general culture of assistants being the 'supply person.'" However, participants did explain that although they make certain purchases, many of these products are used and disposed by others. For instance, one individual explained that "for chemicals after use and gloves after use, the actual students/researchers within the lab make the disposal decisions and decide if something is hazardous."

Moreover, the participants were asked what they do with materials they need to discard or get rid of. They were also asked if they were ever unsure about how to dispose of certain products. A wide range of experiences were reported. Staff members involved in sustainability efforts or scientific laboratories were more aware of disposal rules and programs. For instance, one employee responded, "I usually know, since I am part of EHS. Or I know who to ask." A lab manager and a research scientist both explained that if they are unsure how to dispose of materials they will ask the EHS department. Multiple participants mentioned that they will post unwanted durable goods on the Reuse email list, give away extra food from catered events, and bring lightbulbs and batteries to collection bins at mailrooms. There were multiple allusions to the learning curve involved in disposal and recycling at MIT; one person remarked "When I started working in the building, I didn't know how to discard of certain materials" and another said she didn't know what to do with batteries since her new building's mailroom did not have a battery collection area. Confusion about source-segregation of trash and recycling also came up. This challenge reflects the larger societal issues around recycling, and the common confusion about recycling rules, which change over time and are specific to each municipality or processor.

Furthermore, the participants were asked if, during the purchasing process, they consider what happens to that product at the end of its life – in other words, do they factor in disposal consequences at the time of purchase? Responses to this question were highly variable. Four people said this is not at all a consideration. Four people said this is only occasionally something they consider. Six people said this is sometimes a consideration. Only two people (a lab manager and a safety manager) said that this is frequently a consideration. Apart from their reporting on the frequency of such considerations, the diversity of attitudes surrounding the perceived relevance of disposal to purchasing emerged in responses. For instance, one purchaser said that disposal is "generally not" a consideration, rather "…the most important thing is that the product does the job." Another said: "No, it's not a factor. It is important to get what people want. Everything comes in packaging, but I can't change that." On the other end of the spectrum, one lab manager said, "Yes, I almost always consider disposal, especially if it is toxic! We are dealing with some hazardous products, we work with carcinogens, so I think about it. I care about the health of my lab mates." Intermediate levels of attention to disposal were also voiced - one person mentioned she worked with the university's Green Committee to get rid of Keurig disposable coffee pods to reduce daily waste generation.

Importance of Sustainability

The participants were also asked how, if at all, environmental sustainability impacts their purchase decisions at MIT. About half of respondents said that sustainability or material conservation plays little to no role in their purchasing, while the other said it does play a role. Some also provided reasons for why sustainability is not a consideration; one person explained that there is no option to purchase sustainable alternatives for the chemicals they need. Another person felt that she was not provided enough information to know what products are more sustainable; she said, "It takes time to figure out what products might be more sustainable, and I haven't taken the time to do that. It is something I wish MIT would do. Maybe they could do green labeling in the catalog when you search for certain chemicals." A different participant explained that one barrier to buying more sustainable products was price; when referencing printer paper, he said, "I think the paper we buy has a recycled content, but I don't seek it out… Recycled products in general tend to be pricier." These quotations reflect the emergent theme that the current purchasing process does not facilitate sustainability-oriented behavior.

Others who said they do think about sustainability mentioned that, as a result, they select products such as paper with recycled content, soap and cleaning products that are more natural, disposable items that are recyclable or compostable, appliances that are Energy-Star certified, and chemicals that have a longer shelf life. This diversity of responses is indicative of the diversity of interpretations of what sustainability means for material goods.

The interviewees were also asked how strongly they feel about material conservation and recycling outside of work, and to provide examples. Eleven participants described feeling strongly about material conservation and recycling, while the other five described a low or medium level of commitment. Most, but not all, individuals that reported a high interest in conservation also said they do think about product sustainability in their MIT purchasing. The less conservation-minded individuals reported conflicted feelings on the topic. For instance, one person explained, "I would put myself in the category of wanting to do the right thing, but not always knowing how to do it, especially if it seems complicated." Two others said, "If there is there not a large burden or cost associated with it, I will make the environmental choice," and "We try to be aware of it, but it's not the end-all-be-all decision for us." Fourteen people referenced recycling and composting as examples of their conservation efforts. Seven people mentioned reuse (e.g., washing and reusing Ziploc bags) and opting for reusable items (mugs, shopping bags, etc.) as examples. Only four individuals mentioned waste reduction efforts, which included such behavior as discontinuing the purchase of plastic straws and avoiding packaging.

Potential for Reduction in Purchasing

To understand the purchasers' perception of how much potential there is to reduce purchasing, they were asked if they could purchase a smaller quantity of products, or use products more carefully or for a longer period of time to extend the usable lifetime. There was a mix of positive and negative responses to this question. Multiple people reported there was little to no room for reduction, especially when they are responsible for purchasing for others' research/work needs. One person explained, "There is hardly room to reduce, as little goes to waste. Before buying, especially if I only need a small quantity of a something, I email out to other managers to see if they have extra." Others expressed that some purchases simply are required and cannot be reduced, such as gases. One instructor said that he buys extra materials on purpose, saying, "Redundancy is important because students are on a short timeline; by buying extra, there are spare parts in case a student loses one or blows one up. Anything that goes unused I keep and stockpile for future use."

Some purchasers explained that they feel the culture is the main obstacle inhibiting them from conservation efforts. One participant said "I am trying to get people to reusable plates/forks with limited success. It takes a culture change." In a similar vein, another person said, "I wish some things were culturally common, like refillable pens. But, people like their specific pens."

A few different people brought up purchasing in bulk, but had differing opinions about it. One person mentioned that she doesn't have sufficient room to buy and store items purchased in bulk. Another individual said, "We are careful in that we buy in bulk to save money, but not buy so much that we don't use it." However, others indicated that the economic incentive to buy in bulk was counter-productive for sustainability in that it encourages purchasing more of a given product. One participant said, "I also don't always want to buy a smaller quantity, because it is cheaper in larger quantities."

When asked if they ever buy used or secondhand products for MIT, about two-thirds of the interviewees said no, and one-third said yes. The products they mentioned buying secondhand included scientific equipment, furniture, glassware, cameras, and lenses. There is still significant opportunity for purchasers to increase the percentage of goods they purchase used, rather than new.

In addition, interviewees were asked if they knew of any MIT-offered incentives to eliminate excessive consumption or reduce waste. The intention of this question was to learn how aware of existing programs purchasers are. Half of them said no, they did not think such incentives existed. The other half mentioned various programs and practices such as the MIT reuse email list, the Furniture Exchange, composting in dining halls, water bottle refill stations, and electronic recycling collection. The only mention of an incentive related to purchasing was that the university suggests that they buy recyclable toner cartridges.

Opinions on Sustainable Materials Management Initiatives

The participants were asked what would best enable them or their department to respond to incentives for materials conservation (such as buying only as much as one needs, reusing, or recycling). Six of the purchasers mentioned they would like more information on environmentally-preferred vendors and/or products. For instance, one purchaser said, "It would help to have simplified information, such as a buying or recycling guide. Ideally it would be concise and have general principles." Other similar responses included, "I would like information on what is environmentally preferred. And recommendations on preferred sustainable caterers" and "I would like the contract team to tag items as preferred on [the online catalog] if it is more sustainable, and then I would just buy it."

Another purchaser mentioned that more information on how to manage products at their end-of-life would also be helpful; she said, "I want guidance on how to properly deal with items bought with MIT money, because I feel responsible for anything our office uses that is MIT owned." Aside from information, there was also mention (by a different participant) of wanting MIT to more strongly encourage a "repair culture."

Furthermore, it was noteworthy that three individuals said they would like some system for top-down recognition for materials conservation efforts. One said, "Having acknowledgement that you saved department money does a lot to motivate people." Another person said, "Having direct incentives of some sort would help me - prizes or bonuses." A different purchaser made a related, but slightly different suggestion; she said, "MIT is so stats driven. It would be great to get feedback and a monetary reward for reduction. Measured feedback. A tangible incentive would help the [Principal Investigator] enforce and pay attention to environmental safety."

Other ideas mentioned related to logistical improvements. One scientist said, "I buy a lot of nitrogen gas, which takes up a lot of space. It would be even cheaper if there was a micro-bulk in the building that could supply high-purity gas." She explained that this would cut down on the number of gas cylinders and deliveries that labs in the building would order. Another purchaser responded saying, "I would like there to be stockrooms on campus. Having minimum order sizes can be limiting, so it would be convenient to be able to buy one or two small things from a stockroom."

The participants were asked whether they would or would not support a policy in which MIT required that staff/faculty purchase a certain type of product for the purpose of improving the feasibility of recycling, refurbishment, and repair to extend the life of such products. Seven people said they would support it, two people said they would not, and seven people said they would support such a policy for some, but not all, product categories. The individuals with this third opinion mentioned that products such as computers, which involve technical choices, would not be well suited for that type of policy. However, policies limiting or standardizing purchases of furniture were viewed as more acceptable. Multiple individuals specified that such a policy of standardization would be reasonable, as long as it didn't have unintended negative consequences. One person said, "As long as it doesn't interfere with quality, convenience, and price, I would be okay with it." Another person said, "As long as the function of the product is good, I would be supportive." On the other hand, those that did not support the hypothetical policy made comments, such as, "On a campus like this, I think people automatically resist things like that" and "It is hard for me to support it, because it limits creativity."

Additionally, participants were asked if they would drop off unwanted durable products for recycling, repurposing, or reuse if MIT offered a specific drop-off location in their building. Fourteen people said yes, and one person (a staff member within EHS) said that their building already has this type of designated spot in the basement and it works well. Some comments about such a system included the following: “Having a dedicated space is important. Right now there is a lack of space,” and “I think a physical location would be even easier than an online list.” The only participant that was skeptical said that people in her department currently store unused equipment in the basement, and suggested another system would not be needed. A few participants mentioned existing alternative methods for getting rid of unwanted goods, such as the Reuse email list, Atlas requests for pickup of large electronic waste, and donations through “Choose to Reuse” events.

The participants were also asked whether or not they would use a university-wide online platform in which they could notify the university that they had unwanted durable goods to be picked up. Fifteen of the sixteen participants said yes, and only one said no. A few people mentioned that they would prefer an online platform to a physical drop-off location. Others described specific features of a web platform that would be crucial. One said, “Yes – although it would be logistically important that I don't have to be there for the actual pick up.” Another person said, “There would need to be a graphic user interface and be user friendly.” Lastly, one person said, “If I found out it was reliable I would continue to use it. If it wasn't reliable, I would stop.” The fact that the idea of an online platform for sharing durable goods was viewed so favorably among this group suggests that the larger MIT population would probably make use such a system.

Finally, at the end of the interview, each participant was asked if they had any suggestions for how MIT could help them or others make purchasing and/or disposal decisions that were more sustainable. The most common recommendation was for MIT to flag sustainable or environmentally-preferable products on the online catalog. Five people suggested this. As one person said, “I wish [the online catalog] would show which options are more sustainable. I would like to see some pop-up window, symbols, and suggestions for substitutions about what is environmentally preferred.” Similarly, another purchaser said she would like to see “green product indicators combined with a search filter for sustainable products.” The interviews revealed that several purchasers do not like that it is currently the purchasers’ responsibility to research vendors and products. One participant said, “I would like Procurement and the contracts office to do the research and leg work to identify comparable sustainable products and ensure they are good quality.”

One participant pointed out that having information on sustainable products would not be sufficient; the university also needs to signal to purchasers that sustainable procurement is a priority. She explained, “The challenge is that if the more sustainable product was more costly, I would feel it is important that we get the go-ahead from senior leadership… because only then would I feel comfortable spending the extra money.” This comment draws attention to the importance of synchronizing messaging and incentives across different institute levels when creating policies and programs. Purchasers will be more likely to select environmentally-preferred items if they (1) have the information to make such a choice, and (2) if there is a directive explicitly encouraging the more sustainable option.

Another suggestion for encouraging sustainable purchasing and disposal was to incorporate information on the topic into staff trainings. One person suggested, "The HR welcome packet should have information on recycling, for instance on where to put batteries, so they can learn from the get-go when they start a job here." Similarly, someone else said, "I wish we had a training once a year or something like that about sustainability resources." Other suggestions included having more space for storage, creating a "reuse stockroom for labs," and having some "circulation of unwanted goods between departments."

Conclusions from the Interviews

The sixteen interviews conducted with MIT purchasers were highly informative for understanding behavioral drivers of purchasing, level of interest in and ability to make sustainable purchasing and disposal choices, and receptiveness to potential policies and programs.

The interviews demonstrated that purchasing behavior is impacted by a variety of factors and systems, including:

- Office/university culture
- Personal values
- Purchasing mechanisms
- Habits
- Budgets
- Incentives
- Demand
- Knowledge

Some of the most important findings from the interviews include:

1. MIT has a strong "culture of choice" in which purchasers and product users are accustomed to being able to select any product they want or need, with very few restrictions. Purchasers generally feel they have a high level of freedom in the purchasing process.
2. Purchasers are accustomed to and comfortable with making purchases from MIT-preferred vendors. They view these purchasers as reliable and vetted.
3. The most important factors purchasers consider when making a purchase are: product quality, affordability, delivery time, and the product's suitability for the required task.
4. Purchasers are often, but not always, responsible for disposing of the items they buy. Many wish they had more information about how to dispose of or get rid of items in an environmentally favorable manner.
5. Purchasers generally value sustainability and are accustomed to recycling, but want more information on how to make more sustainable choices. However, purchasers had

mixed levels of receptiveness to the idea of having limited purchasing options for the sake of sustainability.

6. Purchasers would like to have green disposal guides, green buying guides, and sustainable products tagged on the online catalog interface.
7. Purchasers would be motivated by institute- or department-wide recognition for making sustainable purchases or conservation efforts
8. Purchasers want the university to have an explicit directive dictating sustainable purchasing is a priority, since this would allow purchasers to make purchase decisions on the basis of sustainability, even it is more costly.

As is the case with many interview-based studies, the findings might be strengthened by a larger sample size of interviewees. That said, if this interview-based study were to be repeated at another university or organization, the priority should be placed on interviewing a diversity of purchasers with different roles and from different departments (administrators, scientists, instructors, students, operations staff, etc.). This is likely more important than simply interviewing a large number of purchasers.

Additional conclusions from the interviews can be found in Chapter 7 (Discussion and Conclusions). Specifically, that is where the reader can find recommendations pertaining to the design of programs, incentives, and policies for helping purchasers make more sustainable choices.

Chapter 7: Discussion and Conclusions

Chapter 7 Abstract

This chapter contains a discussion of the results of this dissertation, including identification of the most meaningful implications from the material flow analysis and greenhouse gas estimates. The chapter also includes methodological lessons learned from conducting this research, and the predicted generalizability of the methods of analysis. Additionally, it provides recommendations for how MIT can increase the sustainability of its materials management through purchasing policies, organizational changes, and programs. This chapter also provides recommendations for how to improve data collection and management for the purpose of conducting an MFA. Shortcomings of the study, opportunities for improvements, and recommendations for future work are also discussed. Lastly, the author reports personal thoughts and reflections on the process of conducting the project and its implications.

Revisiting the Research Objectives

The original research objectives from Chapter 1 are listed below, and are revisited to briefly address how each objective was met in this thesis.

O1: Characterize the materials flow profile of the campus, revealing consumption patterns for various material groups.
Outcome: This goal was achieved by gathering a diverse collection of data sets, which when pieced together were useful for cataloging the material flows of different material groups. Significant time was spent normalizing product and/or material categories to allow for analysis by category. Consumption patterns were assessed by different lenses, such as temporal variation, purchasing entity, dollar expenditure per category, etc.

O2: Quantify the material inflows, stocks, and outflows in terms of dollar value or mass.
Outcome: This objective was accomplished. Inflows were primarily quantified by dollar value, and a proof-of-concept was used to estimate the mass for a sample of purchases. Stocks were quantified by dollar value at their time of purchase, as well as by the number of units, which are vary in mass per unit. Outflows – mostly waste – were quantified by mass, since such data had been collected by the hauler and the Department of Facilities.

O3: Identify the university processes/activities that have the largest material cost
Outcome: Material cost was measured in the following ways: (1) expenditure by product category, (2) material spend by organizational unit – e.g., dollars spent on material goods by research group, (3) greenhouse gas emissions of purchasing and waste management, allocated by product category.

O4: Characterize the organizational structure (including the degree of centralization) of materials purchasing and disposal decisions on campus.

Outcome: The organizational structure of materials purchasing and disposal was characterized first by conducting in-person interviews, which revealed important qualitative features of the environment, platforms, and values that influence purchasing. The degree of centralization in purchasing was measured by the number of distinct buyers per a given time period of product category. The degree of centralization of disposal decisions was made apparent through discussions with waste-related stakeholders within the university.

O5: Recommend institutional opportunities to increase materials sustainability via institutional policy, organizational changes, or new programs.
Outcome: A set of recommendations is provided in this chapter, and was directly provided to key university decision makers, such as MIT's Office of the Vice President for Finance, the Office of Procurement and Sourcing, and the Office of Sustainability. These recommendations were also summarized in the public dissertation defense, which occurred on March 6, 2020.

Methodological Learnings and Contributions

This research demonstrates that MFA can be applied at the university-level, and provides a general procedure for how to do so. To carry out the MFA, material flows were characterized using a combination of product and material categories, and a new, university-specific material taxonomy was created. This case study demonstrates that an MFA of a university requires the use of a portfolio of diverse methods, which deliver different outcomes that then must be pieced together.

Specifically, the collection of methods used in this study were the following:

- General Data Analysis:
  - Statistical analysis
  - Data visualization
- Organizational/Behavioral Analysis:
  - In-person interviews
  - Coding of interviews
- Categorization of flows
  - Development of a custom material taxonomy
- Analysis of Material Inflows
  - Natural language processing
- Analysis of Material Stocks
  - Calculation of product lifetimes
- Analysis of Material Outflows
  - Waste audits
- Environmental Impact Analysis
  - Adapted version of Economic-Input Output Life Cycle Assessment
  - EPA Waste Reduction Model (WARM)

While these exact methods are not required to conduct an MFA of a university, it is clear that a systems-oriented approach and a set of interdisciplinary methods are needed to characterize the material flows of a complex institution.

This study illustrates that carrying out an MFA for a university campus can be challenging. Below are some of the most significant challenges, along with strategies implemented by the author to overcome the obstacles to performing an MFA of a university.

<u>Data Sharing Concerns</u>

> **Challenge:** University administrators and operations staff were reluctant to share data, due to concerns about data security and potential misuse.
>
> **Strategy:** The author formed connections with operational and administrative entities within the university that were involved in the collection and management of institutional data. It was also mutually beneficial to develop a working partnership with the relevant entities guiding sustainability commitments, including academic research groups and the university's Office of Sustainability. Furthermore, the author found it helpful to inform senior financial administrators about the project and generate excitement about the research – these administrators were the individuals who were positioned to approve the sharing of data with the researcher and implement recommendations arising from the project's findings.

<u>Lack of Data Governance</u>

> **Challenge:** There were no existing procedures and rules concerning the collection and use of data (coming from several different offices and departments) for academic research. Despite there being a clear presence of data, the ownership of and policies for sharing that data were unclear (i.e., lack of data governance).
>
> **Strategy:** The author worked with administrators and university lawyers to develop a Memorandum of Understanding (MOU) that outlined a contractual agreement for data sharing and use. An MOU enabled the author to do her research, but came at significant cost in terms of time and bureaucratic delays. In addition, the author maximized security by accessing the data via password-protected databases that were stored on secure, MIT servers. She avoided storing data locally. To easily access the data, she utilized a web-enabled platform for analyzing and visualizing data (Tableau). This platform also allowed for easy sharing of findings with colleagues.

<u>System Complexity</u>

> **Challenge:** Measuring material inflows is especially complex, because there are multiple ways to purchase goods for/at the university, and because MIT does not collect product weights.

Strategy: One lesson learned from this project is that quantifying the mass and material flows from inflows and stocks is much more difficult than it is for outflows. In order to cope with the limited data and complexity of the system, the author decided to streamline the data collection process as much as possible. She prioritized (1) using centralized data sources over decentralized, (2) capturing large material flows over small flows, and (3) normalizing the flows by dollar value instead of mass.

<u>**Data Quality**</u>

Challenge: The data sets were in a variety of formats, incomplete, and difficult to process.

Strategy: The author recruited help from other individuals with useful data manipulation skills. For instance, she hired an undergraduate majoring in computer science as a research assistant to help with data processing. This interdisciplinary collaboration resulted in a novel application of natural language processing, and also allowed for more efficient division of labor.

Generalizability of Methods of Analysis

Specific MFA findings of this study will likely be most similar to other technical universities with large science and engineering programs. However, the methods are relevant for a wider set of institutions. Although the structure of every university is somewhat different, the primary methods utilized in this study can be applied to any university campus seeking to do an MFA. Undoubtedly, there are some universally purchased material streams (such as paper, furniture, printer toner, and computers) among colleges and universities. Furthermore, the analysis used in this study may translate well for analyzing the material flows of corporate campuses.

It is possible that there is a minimum set of activities that characterize university material consumption, storage of materials, and dispersion of wastes. However, since this dissertation is primarily a case study of one university, it cannot identify this exact set of activities, or global indicators of material intensity.

To maximize chances of success, any university conducting this a project of this size should ideally have cooperation from the following stakeholders:

1. The group(s) working on sustainability of campus operations (e.g., Office of Sustainability)
2. The group that oversees procurement and/or sourcing of products
3. A project lead who can dedicate time and energy to getting to know the campus system
4. An organization or individual committed to funding for the project
5. High-level administrators, who will provide authority for data sharing

Recommendations and Opportunities for Improvement

This section offers two general categories of recommendation – one relating to data collection and management, and another relating to institutional behavior and policies. The diversity of these recommendations stems from the fact that this work not only advanced academic research, but also served as opportunity to use a university campus as a living lab, or testbed.

Recommendations for Data Collection and Management

1. Start the process of data collection early, as there may be a large lead time to acquire purchase record data. It may also take time to develop relationships with different departments/ entities on campus.
2. The following purchase record attributes will likely be of value for carrying out an MFA with an environmental impact analysis:
    - Product Description
    - Quantity
    - Purchase Date
    - Product Category (e.g., UNSPSC or SKU)
    - Supplier
    - Manufacturer
    - Purchasing entity
    - Price
    - Shipping and/or product weight
    - Packaging weight and material
    - Manufacturer origin and shipping method
    - If available, product material or bill of materials
    - Product certifications for stewardship / sustainability
3. Identify an individual or small group of individuals to manage all of the MFA data. Having a dedicated data manager will improve consistency, maintenance of privacy, and ease of sharing. Furthermore, it will make it easier to repeat a project like this in an attempt to measure change over time.
4. Connect with suppliers, as they often hold more specific information on material goods purchases than the university. However, the university may not receive that highly detailed information unless it requests it.

Recommendations for Organizational Policies and Materials Management Strategies

The list below are the author's recommendations for organizational policies and materials management strategies based on her findings from the MFA. While these recommendations are based on the case study of MIT's material flows, many of them are likely applicable to other universities.

1. Improve and increase resource sharing within the university
    - Encourage the use of online sharing or reuse platform. These platforms might require a university login and might be managed by a university committee or existing office (e.g., Property Office or EHS)
    - Create a web-based intra-university chemical inventory. Having an organized, up-to-date digital chemical inventory system would better enable safe chemical sharing. Such a system would allow labs to first check to see if another lab or group has a surplus of a particular chemical before making a purchase. Increasing chemical sharing not only avoids unnecessary purchasing, but would reduce the quantity of hazardous waste due to the disposal of expired chemicals.
    - Establish better communication between departments regarding material/product inventories. At present, material resource sharing between departments and within departments/units is not formalized. Currently, at MIT, inventory information is only maintained at the department or group level. This is likely due to the fact that departments or labs have separate budgets because of the institutional financial structure. If the university creates formal mechanisms to encourage departments to consider the larger community as a resource for materials sharing, the entire system can achieve more efficient material allocation/use.

2. Establish contracts with major suppliers that include sustainability language and require the provision of high quality data.
    - The specific sustainability language included should reflect the institute's priorities relating to material consumption and environmental impacts.
    - This language might be developed by a committee including: lawyers, procurement and sourcing staff, staff from the Office of Sustainability, researchers with relevant expertise, and purchasers familiar with the purchasing system.

3. Incentivize sustainability-oriented purchasing.
    - Label environmentally preferred products on the online purchasing platform.
    - Make it easier to purchase second-hand and refurbished products.

- Enable bulk purchasing (aggregated for multiple purchases) of ubiquitous items. Bulk purchasing should only be encouraged for products that are frequently purchased and are often used in large quantities. Bulk purchasing should only be encouraged for products that have long shelf lives and are easily stored (e.g., no refrigeration needed). Bulk purchasing would avoid repeated purchases that consume energy from shipping.
- Vet products / suppliers with environmental stewardship.
- Subsidize or mandate products that are environmentally preferable without compromising quality / function.

4. Reduce packaging of purchased goods.
    - Establish or expand on-campus stockrooms for the distribution of commonly-purchased products. There might be a few types of stockrooms strategically located on campus near the end-user. For instance, a university like MIT might have a lab supply stockroom that carries lab gloves, pipette tips, petri dishes, etc., as well as an office supply stockroom that carries printer paper, staples, and printer ink.

5. Maintain better data on material stocks for the purpose of tracking and sharing.
    - Create and record a “chain of custody” for material-intensive purchases, even if those products are low in dollar value. Given that the individual making a purchase may not be the end user of the product, it would be helpful to track which individuals are responsible for storing and disposing of a product.

Future Research

Ideally, conducting an MFA of a university would involve high quality data, significant financial resources, and substantial time. Such conditions might allow for more detailed and/or extensive MFA results. For instance, with a greater budget, more waste audits could be carried out using paid labor or waste consulting services. This might increase the accuracy of composition averages and provide higher-resolution material categories as needed. With additional data on donations and resale, one could estimate the mass of materials leaving the university as donations or items for future reuse outside the institute. These goods include collected items from book drives, student move-in and move-out days, and other reuse channels. Lastly, and most importantly, if the university were to require its vendors to provide more information on the products purchased by MIT, researchers could much more efficiently conduct an MFA. In particular, this would be made easier with specific information about product type, product weight, and material type and/or bill of materials.

There are many opportunities for future research that would expand on or complement the body of work presented in this dissertation. Some of these possible opportunities are listed below:

- Establish methods for identifying material type of procured products
- Establish a method for estimating the mass/weights of procured products (having shipping weights makes this much easier)
- Estimate the quantity of material stocks on campus for purchased goods that are not tracked by the accounting/audit office
- Analyze other environmental impacts from material consumption (e.g., human toxicity)
- Repeat the MFA for MIT for another year (e.g., 2022)
- Conduct MFAs for a diversity of colleges and universities and compare them to learn how material consumptions varies by technical/non-technical, urban/rural, research/liberal-arts
- Conduct case studies about specific material categories (e.g., paper products, lab equipment). This might better enable accurate life cycle analyses or allow for researchers to identify more specific products that are problematic.

Conclusions

Measuring Impact

This research measured the environmental impact of purchasing and waste disposal using global warming potential, or greenhouse gas emissions. Although this is an important metric of environmental impact, it is only one of many possible metrics one might use. Going forward, it will be important for MIT and other universities assessing their materials footprint to determine which metrics are more relevant to them and the variety of materials they consume.

Some examples of other environmental metrics that might be of relevance are listed below. Each metric is also labeled as either negative or positive. A negative measure is one that we aim to minimize. A positive measure is one that we aim to maximize.

- Embodied energy (negative measure)
- Quantity of waste generated (negative measure)
- Percentage of outflows recycled, reused, resold (positive measure)
- Use lifetimes of products by type (positive measure)
- Percentage of waste reduced (positive measure)
- Percentage of purchases made from renewable materials (positive measure)
- Percentage of purchases made from recycled content (positive measure)
- Use of fossil fuels or other non-renewables (negative measure)
- Toxic impact on humans (negative measure)
- Toxic impact on ecosystems and organisms, known as Ecotoxicity (negative measure)

Selection of these environmental metrics may be overwhelming, due to the quantity and specificity of data needed to measure them. Still, universities can narrow the scope of their impact assessment by first identifying their own priorities. For instance, a university might benefit from going through the exercise of prioritizing the following environmentally-related goals, so as to then better select meaningful metrics:

- Eliminate unfavorable (e.g., toxic, non-renewable, scarce) materials
- Improve recovery infrastructure
- Increase recycling / source segregation
- Improve material efficiency
- Increase resource sharing
- Minimize local environmental impacts (e.g., air pollution)
- Minimize global environmental impacts (e.g., climate change)

It should be noted that, beyond environmental impact, there are other potentially important metrics available for assessing social and economic issues. For instance, universities might be interested in (a) analyzing purchasing from the perspective of women- and minority-owned businesses, (b) sourcing from local businesses, or (c) avoiding child-labor through responsible sourcing.

In addition to identifying the metrics of interest, a university conducting an MFA should also take time to consider what material flows they are most able to realistically change. The research group should think about what materials/products are the least essential and/or unimportant to the university's mission and daily functions. Even though MIT has a long-standing culture of choice with regard to purchasing, for some less essential products that have basic functions, a policy for purchasing a particular type or quantity might have minimal impact on purchasers and institute's mission. The university should also identify the material streams they believe are most problematic (be it for cost, environmental impact, etc.). It may be most useful for the research group to perform this exercise at the start and end of the MFA process. This process can help to shape the focus of the MFA, as well as the policy recommendations that come out of the study.

Perspective of the Researcher

Conducting a material flow analysis of my home university was a giant undertaking. I learned how the institute collects and manages data, how it functions organizationally, and how operational and academic priorities differ. After four years of working on this project, I have learned that conducting an MFA of a university campus is challenging if sufficient data is not available.

A few of my findings and observations have generated some pessimism. It became clear to me that the university's procurement and waste management s are disconnected and do not have sufficient incentives to connect for the sake of efficient materials management. Additionally, the university's lack of commitment to collecting and managing high quality data was disappointing – especially given that MIT has such vast technical resources in data science. Furthermore, I noticed that there were competing interests among different stakeholders and a prevailing priority of cost-savings among different groups. This suggests that there needs to be a directive and prioritization of sustainable materials management from the highest level administrators of the university.

However, generally, I am optimistic about the future of MIT's materials management. Although MIT has a long way to go to becoming efficient in its material consumption, I believe there are paths forward to improvement. University purchasers care about sustainability and want to know how to change their behavior via environmentally-oriented purchasing and disposal. Furthermore, MIT's Office of Sustainability and the Environmental Solutions Initiative have shown strong interest in and dedication to sustainable materials management. This bodes well for the recommendations being implemented by MIT in the near future.

The Way Forward

The qualitative and quantitative data, as well as anecdotal observations, indicate that MIT has a linear economy. In other words, most materials are purchased, used, and thrown away. For MIT to achieve a more sustainable system of materials management, it must transition toward a circular economy. In a circular economy, materials are in use for as long as possible and their value is maximized during this use phase. Then at the end of their useful life, the materials are recovered and recycled and/or remanufactured into new products. Reuse, resource sharing, and the utilization of secondhand markets are crucial to such a system.

Figure 32 shows a vision of what material flows might look like in a university campus aspiring to transition toward a circular economy. In this more sustainable scenario, the university reduces its inflows and outflows, and increases the quality (and perhaps size) of its stocked resources. By keeping this stock well-inventoried, the university can keep track of what it already has and maximize the utility of each product. Intra-university reuse and resource sharing would be emphasized. Whenever possible, unwanted materials would be sent back to manufacturers that have Extended Producer Responsibility programs. Alternatively, some waste streams might be managed locally via decentralized waste management (e.g., small-scale anaerobic digestion of food waste).

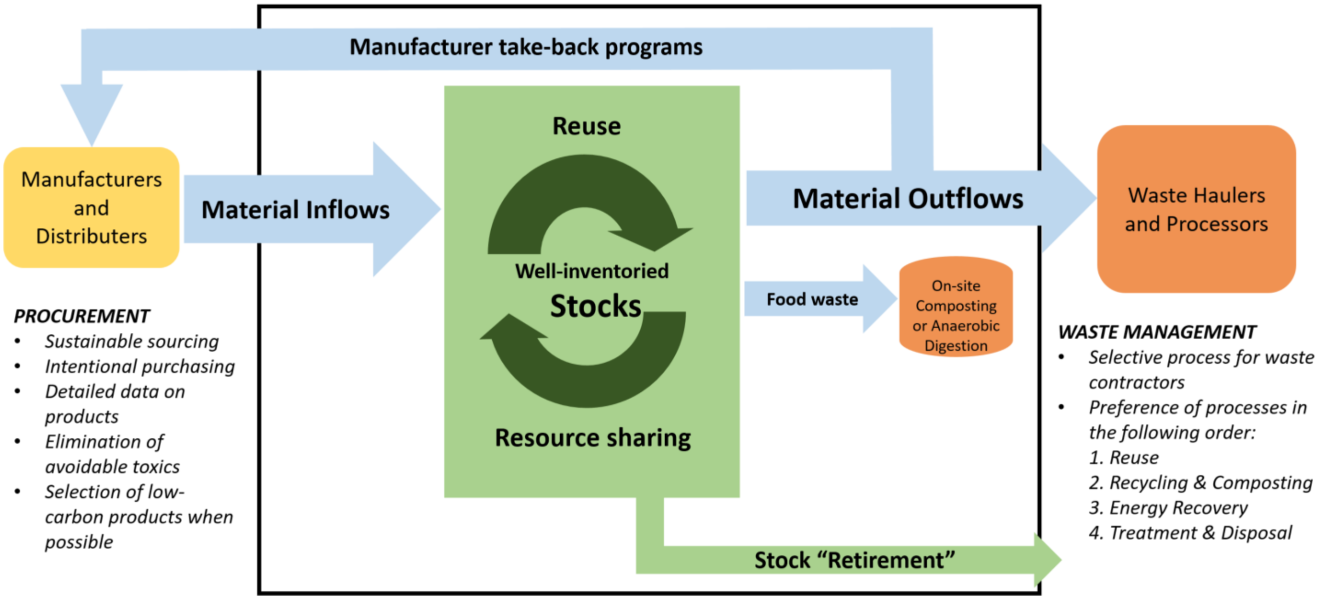


Figure 32: A system diagram of a university campus that more closely resembles a circular economy of materials management.

With adequate data, collaboration between stakeholders, and knowledge of baseline material flows, I believe MIT and other universities can make substantial improvements in the sustainability of their materials management systems.

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Appendices

Below are a set of appendices. They include large tables, more detailed information, photos, and full version of methods used in this thesis, which were too large or cumbersome to include in the main body of the thesis.

1. Material Taxonomy

This is the full material taxonomy created by the author. Its categories use a hybrid of product and material descriptions. It was designed specifically to characterize the material flows of a university campus. This taxonomy can be digitally provided by the author, Rachel Perlman, by request.

Code Level 1	Title Level 1	Code Level 2	Title Level 2	Code Level 3	Title Level 3	Code Level 4	Title Level 4	Code Level 5	Title Level 5
MF.1	Biomass	MF.1.1	Crops	MF.1.1.1	Cereals				
MF.1	Biomass	MF.1.1	Crops	MF.1.1.2	Roots, tubers				
MF.1	Biomass	MF.1.1	Crops	MF.1.1.3	Sugar crops				
MF.1	Biomass	MF.1.1	Crops	MF.1.1.4	Pulses				
MF.1	Biomass	MF.1.1	Crops	MF.1.1.5	Nuts				
MF.1	Biomass	MF.1.1	Crops	MF.1.1.6	Oil-bearing crops				
MF.1	Biomass	MF.1.1	Crops	MF.1.1.7	Vegetables				
MF.1	Biomass	MF.1.1	Crops	MF.1.1.8	Fruits				
MF.2	Biomass	MF.1.1	Crops	MF.1.1.9	Coffee				
MF.3	Biomass	MF.1.1	Crops	MF.1.1.10	Tea				
MF.4	Biomass	MF.1.1	Crops	MF.1.1.11	Chocolate				
MF.5	Biomass	MF.1.1	Crops	MF.1.1.12	Candy				
MF.1	Biomass	MF.1.1	Crops	MF.1.1.13	Fibers				
MF.1	Biomass	MF.1.1	Crops	MF.1.1.14	Tobacco				
MF.1	Biomass	MF.1.1	Crops	MF.1.1.15	Cotton				
MF.1	Biomass	MF.1.1	Crops	MF.1.1.16	Flax				
MF.1	Biomass	MF.1.1	Crops	MF.1.1.17	Hemp				
MF.1	Biomass	MF.1.1	Crops	MF.1.1.18	Jute				
MF.1	Biomass	MF.1.1	Crops	MF.1.1.19	Kenaf				
MF.1	Biomass	MF.1.1	Crops	MF.1.1.20	Famie				
MF.1	Biomass	MF.1.1	Crops	MF.1.1.21	Sisal				
MF.1	Biomass	MF.1.1	Crops	MF.1.1.22	Other crops (excluding fodder crops)				
MF.1	Biomass	MF.1.2	Crop residues (used), fodder crops, grazed biomass	MF.1.2.1	Straw				

MF.1	Biomass	MF.1.2	Crop residues (used), fodder crops, grazed biomass	MF.1.2.2	Other crop residues (sugar and fodder beet leaves, etc.)
MF.1	Biomass	MF.1.2	Crop residues (used), fodder crops, grazed biomass	MF.1.2.3	Fodder crops
MF.1	Biomass	MF.1.2	Crop residues (used), fodder crops, grazed biomass	MF.1.2.4	Grazed biomass
MF.1	Biomass	MF.1.3	Wood or wood-derived products	MF.1.3.1	Wood (solid)
MF.1	Biomass	MF.1.3	Wood or wood-derived products	MF.1.3.2	Plywood
MF.1	Biomass	MF.1.3	Wood or wood-derived products	MF.1.3.3	Cork
MF.1	Biomass	MF.1.3	Wood or wood-derived products	MF.1.3.4	Paper
MF.1	Biomass	MF.1.3	Wood or wood-derived products	MF.1.3.5	Cardstock
MF.1	Biomass	MF.1.3	Wood or wood-derived products	MF.1.3.6	Cardboard
MF.1	Biomass	MF.1.3	Wood or wood-derived products	MF.1.3.7	Boxboard
MF.1	Biomass	MF.1.3	Wood or wood-derived products	MF.1.3.8	Paper towels
MF.1	Biomass	MF.1.3	Wood or wood-derived products	MF.1.3.9	Toilet paper
MF.1	Biomass	MF.1.3	Wood or wood-derived products	MF.1.3.10	Paper tissue or napkins
MF.1	Biomass	MF.1.4	Wild fish catch, aquatic plants and animals	MF.1.4.1	Wild fish catch
MF.1	Biomass	MF.1.4	Wild fish catch, aquatic plants and animals	MF.1.4.2	All other aquatic animals and plants
MF.1	Biomass	MF.1.5	Live animals and animal products	MF.1.5.1	Meat and meat preparations
MF.1	Biomass	MF.1.5	Live animals and animal products	MF.1.5.2	Dairy products, birds, eggs and honey
MF.1	Biomass	MF.1.5	Live animals and animal products	MF.1.5.3	Animal fibers, skins, furs, leather, etc.
MF.1	Biomass	MF.1.6	Products mainly from biomass		
MF.1	Biomass	MF.1.7	Food waste (mixed)		

MF.1	Biomass	MF.1.8	Yard waste	MF.1.8.1	Grass clippings
MF.1	Biomass	MF.1.8	Yard waste	MF.1.8.2	Leaf waste
MF.1	Biomass	MF.1.8	Yard waste	MF.1.8.2	Branches and other debris
MF.2	Metals	MF.2.1	Ferrous metal	MF.2.1.1	Iron
MF.2	Metals	MF.2.1	Ferrous metal	MF.2.1.2	Steel
MF.2	Metals	MF.2.1	Ferrous metal	MF.2.1.3	Stainless Steel
MF.2	Metals	MF.2.2	Non-ferrous metal	MF.2.2.1	Copper
MF.2	Metals	MF.2.2	Non-ferrous metal	MF.2.2.2	Nickel
MF.2	Metals	MF.2.2	Non-ferrous metal	MF.2.2.3	Lead
MF.2	Metals	MF.2.2	Non-ferrous metal	MF.2.2.4	Zinc
MF.2	Metals	MF.2.2	Non-ferrous metal	MF.2.2.5	Tin
MF.2	Metals	MF.2.2	Non-ferrous metal	MF.2.2.6	Gold, silver, platinum and other precious metals
MF.2	Metals	MF.2.2	Non-ferrous metal	MF.2.2.7	Aluminum
MF.2	Metals	MF.2.2	Non-ferrous metal	MF.2.2.8	Uranium and thorium
MF.2	Metals	MF.2.2	Non-ferrous metal	MF.2.2.9	Other non-ferrous metals
MF.2	Metals	MF.2.3	Products mainly from metals		
MF.2	Metals	MF.2.4	Mixed scrap metal		
MF.2	Metals	MF.2.5	Unspecified metal		
MF.3	Non-metallic inorganics	MF.3.1	Marble, granite, sandstone, porphyry, basalt, other ornamental or building stone (excluding slate)		
MF.3	Non-metallic inorganics	MF.3.2	Chalk and dolomite		
MF.3	Non-metallic inorganics	MF.3.3	Slate		
MF.3	Non-metallic inorganics	MF.3.4	Chemical and fertilizer minerals		
MF.3	Non-metallic inorganics	MF.3.5	Salts		
MF.3	Non-metallic inorganics	MF.3.6	Limestone and gypsum		
MF.3	Non-metallic inorganics	MF.3.7	Clays and kaolin		
MF.3	Non-metallic inorganics	MF.3.8	Sand and gravel		
MF.3	Non-metallic inorganics	MF.3.9	Other non-metallic minerals		
MF.3	Non-metallic inorganics	MF.3.10	Excavated earthen materials (including soil)		

MF.3	Non-metallic inorganics	MF.3.11	Products mainly from non-metallic minerals		
MF.3	Non-metallic inorganics	MF.3.12	Glass	MF.3.12.1	Glass containers
MF.3	Non-metallic inorganics	MF.3.12	Glass	MF.3.12.2	Glass windows
MF.3	Non-metallic inorganics	MF.3.12	Glass	MF.3.12.3	Glass mirror
MF.3	Non-metallic inorganics	MF.3.12	Glass	MF.3.12.4	Glass lenses
MF.3	Non-metallic inorganics	MF.3.12	Glass	MF.3.12.5	Other glass
MF.3	Non-metallic inorganics	MF.3.13	Water		
MF.4	Fossil energy materials/carriers	MF.4.1	Coal and other solid energy materials/carriers	MF.4.1.1	Lignite (brown coal)
MF.4	Fossil energy materials/carriers	MF.4.1	Coal and other solid energy materials/carriers	MF.4.1.2	Hard coal
MF.4	Fossil energy materials/carriers	MF.4.1	Coal and other solid energy materials/carriers	MF.4.1.3	Oil shale and tar sands
MF.4	Fossil energy materials/carriers	MF.4.1	Coal and other solid energy materials/carriers	MF.4.1.4	Peat
MF.4	Fossil energy materials/carriers	MF.4.2	Liquid and gaseous energy materials/carriers	MF.4.2.1	Crude oil, condensate and natural gas liquids (NGL)
MF.4	Fossil energy materials/carriers	MF.4.2	Liquid and gaseous energy materials/carriers	MF.4.2.2	Natural gas
MF.4	Fossil energy materials/carriers	MF.4.3	Products mainly from fossil energy products		
MF.5	Plastics	MF.5.1	Acrylonitrile butadiene styrene (ABS)		
MF.5	Plastics	MF.5.2	Polyamide (PA)		
MF.5	Plastics	MF.5.3	Polypropylene (PP)		
MF.5	Plastics	MF.5.4	Polyethylene terephthalate (PET)		
MF.5	Plastics	MF.5.5	Polyethylene (PE)	MF.5.5.1	High density polyethylene (HDPE)
MF.5	Plastics	MF.5.5	Polyethylene (PE)	MF.5.5.2	Low density polyethylene (LDPE), including film plastic
MF.5	Plastics	MF.5.6	Polyvinyl chloride (PVC)		
MF.5	Plastics	MF.5.7	Polystyrene (PS)		
MF.5	Plastics	MF.5.8	Polylactide (PLA)		

MF.5	Plastics	MF.5.9	Polyhydroxybutyrate (PHB)		
MF.5	Plastics	MF.5.10	Epoxy		
MF.5	Plastics	MF.5.11	Polyester		
MF.5	Plastics	MF.5.12	Phenolic		
MF.5	Plastics	MF.5.13	Natural rubber (NP)		
MF.5	Plastics	MF.5.14	Butyl rubber (BR)		
MF.5	Plastics	MF.5.15	Ethylene-vinyl acetate (EVA)		
MF.5	Plastics	MF.5.16	Polychloroprene (CR)		
MF.5	Plastics	MF.5.17	Nitrile		
MF.5	Plastics	MF.5.18	Latex		
MF.5	Plastics	MF.5.19	Silicone		
MF.5	Plastics	MF.5.20	Neoprene		
MF.5	Plastics	MF.5.21	Chloroprene		
MF.5	Plastics	MF.5.22	Trionic		
MF.5	Plastics	MF.5.23	Acrylic		
MF.5	Plastics	MF.5.24	Polyurethane		
MF.5	Plastics	MF.5.25	Thermoplastic		
MF.5	Plastics	MF.5.26	Unspecified Plastic or Polymer		
MF.6	Chemicals and compressed gas	MF.6.1	Pyrophoric		
MF.6	Chemicals and compressed gas	MF.6.2	Water-reactive		
MF.6	Chemicals and compressed gas	MF.6.3	Explosives	MF.6.3.1	Potentially explosive compound classes
MF.6	Chemicals and compressed gas	MF.6.3	Explosives	MF.6.3.2	Explosive Salts
MF.6	Chemicals and compressed gas	MF.6.3	Explosives	MF.6.3.3	Potentially explosive chemical
MF.6	Chemicals and compressed gas	MF.6.4	Acute toxic chemicals		

MF.6	Chemicals and compressed gas	MF.6.5	Acute toxic gas				
MF.6	Chemicals and compressed gas	MF.6.6	Peroxide Formers	MF.6.6.1	Class 1		
MF.6	Chemicals and compressed gas	MF.6.6	Peroxide Formers	MF.6.6.2	Class 2		
MF.6	Chemicals and compressed gas	MF.6.6	Peroxide Formers	MF.6.6.3	Class 3		
MF.6	Chemicals and compressed gas	MF.6.7	Corrosives	MF.6.7.1	Strong acids	MF.6.7.1.1	Nitric acid
MF.6	Chemicals and compressed gas	MF.6.7	Corrosives	MF.6.7.1	Strong acids	MF.6.7.1.2	Sulphuric acid
MF.6	Chemicals and compressed gas	MF.6.7	Corrosives	MF.6.7.1	Strong acids	MF.6.7.1.3	Hydrochloric acid
MF.6	Chemicals and compressed gas	MF.6.7	Corrosives	MF.6.7.1	Strong acids	MF.6.7.1.4	Acedic acid
MF.6	Chemicals and compressed gas	MF.6.7	Corrosives	MF.6.7.2	Strong bases	MF.6.7.2.1	Sodium hydroxide
MF.6	Chemicals and compressed gas	MF.6.7	Corrosives	MF.6.7.2	Strong bases	MF.6.7.2.2	Potassium hydroxide
MF.6	Chemicals and compressed gas	MF.6.7	Corrosives	MF.6.7.2	Strong bases	MF.6.7.2.3	Ammonium hydroxide
MF.6	Chemicals and compressed gas	MF.6.7	Corrosives	MF.6.7.2	Strong bases	MF.6.7.2.4	Ammonia
MF.6	Chemicals and compressed gas	MF.6.8	Oxidizing agents				
MF.6	Chemicals and compressed gas	MF.6.9	Reducing agents				
MF.6	Chemicals and compressed gas	MF.6.10	Regulated carcinogens				
MF.6	Chemicals and compressed gas	MF.6.11	Antibodies				
MF.6	Chemicals and compressed gas	MF.6.12	Enzymes (polymerase, ligase etc)				
MF.6	Chemicals and compressed gas	MF.6.13	Cultures and fluids				
MF.6	Chemicals and compressed gas	MF.6.14	Cross linking agents				
MF.6	Chemicals and compressed gas	MF.6.15	Cytology reagents or solutions or stains (bio)				
MF.6	Chemicals and compressed gas	MF.6.16	Eucariotic transfection reagents (bio)				
MF.6	Chemicals and compressed gas	MF.6.17	Polymerics (for making gels, columns)				
MF.6	Chemicals and compressed gas	MF.6.18	Media ingredients				

MF.6	Chemicals and compressed gas	MF.6.19	Carbohydrates				
MF.6	Chemicals and compressed gas	MF.6.20	Lipids				
MF.6	Chemicals and compressed gas	MF.6.21	Proteins				
MF.6	Chemicals and compressed gas	MF.6.22	Nucleic Acids				
MF.6	Chemicals and compressed gas	MF.6.23	Ligands				
MF.7	Chemicals and compressed gas	MF.6.24	Buffers				
MF.6	Chemicals and compressed gas	MF.6.25	Organic Solvents	MF.6.25.1	Alcohols	MF.6.25.1.1	Ethyl Alcohol (hand sanitizer)
MF.6	Chemicals and compressed gas	MF.6.25	Organic Solvents	MF.6.25.1	Alcohols	MF.6.25.1.2	Ethanol
MF.6	Chemicals and compressed gas	MF.6.25	Organic Solvents	MF.6.25.1	Alcohols	MF.6.25.1.3	Methanol
MF.6	Chemicals and compressed gas	MF.6.25	Organic Solvents	MF.6.25.1	Alcohols	MF.6.25.1.4	Isopropyl
MF.6	Chemicals and compressed gas	MF.6.25	Organic Solvents	MF.6.25.1	Alcohols	MF.6.25.1.5	Propanol
MF.6	Chemicals and compressed gas	MF.6.25	Organic Solvents	MF.6.25.1	Alcohols	MF.6.25.1.6	Butanol
MF.6	Chemicals and compressed gas	MF.6.25	Organic Solvents	MF.6.25.1	Alcohols	MF.6.25.1.7	Polyvinyl
MF.6	Chemicals and compressed gas	MF.6.25	Organic Solvents	MF.6.25.1	Alcohols	MF.6.25.1.8	BDH
MF.6	Chemicals and compressed gas	MF.6.25	Organic Solvents	MF.6.25.1	Alcohols	MF.6.25.1.9	Benzyl
MF.6	Chemicals and compressed gas	MF.6.25	Organic Solvents	MF.6.25.1	Alcohols	MF.6.25.1.10	N-propyl
MF.6	Chemicals and compressed gas	MF.6.25	Organic Solvents	MF.6.25.1	Alcohols	MF.6.25.1.11	Other Alcohol
MF.6	Chemicals and compressed gas	MF.6.25	Organic Solvents	MF.6.25.2	Ketones		
MF.6	Chemicals and compressed gas	MF.6.25	Organic Solvents	MF.6.25.3	Aldehydes		
MF.6	Chemicals and compressed gas	MF.6.25	Organic Solvents	MF.6.25.4	Glycol ethers		
MF.6	Chemicals and compressed gas	MF.6.25	Organic Solvents	MF.6.25.5	Esters		
MF.6	Chemicals and compressed gas	MF.6.25	Organic Solvents	MF.6.25.6	Glycol ether esters		
MF.6	Chemicals and compressed gas	MF.6.25	Organic Solvents	MF.6.25.7	Aliphatic		

MF.6	Chemicals and compressed gas	MF.6.25	Organic Solvents	MF.6.25.8	Aromatic
MF.6	Chemicals and compressed gas	MF.6.25	Organic Solvents	MF.6.25.9	Chlorinated hydrocarbons
MF.6	Chemicals and compressed gas	MF.6.25	Organic Solvents	MF.6.25.10	Brominated hydrocarbons
MF.6	Chemicals and compressed gas	MF.6.26	Compressed Gas	MF.6.26.1	Acetylene
MF.6	Chemicals and compressed gas	MF.6.26	Compressed Gas	MF.6.26.2	Compressed Air
MF.6	Chemicals and compressed gas	MF.6.26	Compressed Gas	MF.6.26.3	Ammonia
MF.6	Chemicals and compressed gas	MF.6.26	Compressed Gas	MF.6.26.4	Argon
MF.6	Chemicals and compressed gas	MF.6.26	Compressed Gas	MF.6.26.5	Carbon dioxide
MF.6	Chemicals and compressed gas	MF.6.26	Compressed Gas	MF.6.26.6	Carbon monoxide
MF.6	Chemicals and compressed gas	MF.6.26	Compressed Gas	MF.6.26.7	Deuterium
MF.6	Chemicals and compressed gas	MF.6.26	Compressed Gas	MF.6.26.8	Ethane
MF.6	Chemicals and compressed gas	MF.6.26	Compressed Gas	MF.6.26.9	Ethylene
MF.6	Chemicals and compressed gas	MF.6.26	Compressed Gas	MF.6.26.10	Helium
MF.6	Chemicals and compressed gas	MF.6.26	Compressed Gas	MF.6.26.11	Hydrogen
MF.6	Chemicals and compressed gas	MF.6.26	Compressed Gas	MF.6.26.12	Krypton
MF.6	Chemicals and compressed gas	MF.6.26	Compressed Gas	MF.6.26.13	Methane
MF.6	Chemicals and compressed gas	MF.6.26	Compressed Gas	MF.6.26.14	Mixture
MF.6	Chemicals and compressed gas	MF.6.26	Compressed Gas	MF.6.26.15	Nitric Oxide
MF.6	Chemicals and compressed gas	MF.6.26	Compressed Gas	MF.6.26.16	Nitrogen
MF.6	Chemicals and compressed gas	MF.6.26	Compressed Gas	MF.6.26.17	Nitrous Oxide
MF.6	Chemicals and compressed gas	MF.6.26	Compressed Gas	MF.6.26.18	Octafluorocyclobutane
MF.6	Chemicals and compressed gas	MF.6.26	Compressed Gas	MF.6.26.19	Oxygen
MF.6	Chemicals and compressed gas	MF.6.26	Compressed Gas	MF.6.26.20	Propane

MF.6	Chemicals and compressed gas	MF.6.26	Compressed Gas	MF.6.26.21	Propylene
MF.6	Chemicals and compressed gas	MF.6.26	Compressed Gas	MF.6.26.22	Sufur Dioxide
MF.6	Chemicals and compressed gas	MF.6.26	Compressed Gas	MF.6.26.23	Sulfur Hexafluroide
MF.6	Chemicals and compressed gas	MF.6.26	Compressed Gas	MF.6.26.24	Sulfur Hexafluroide / Argon mix
MF.6	Chemicals and compressed gas	MF.6.26	Compressed Gas	MF.6.26.25	Other compressed gas
MF.6	Chemicals and compressed gas	MF.6.27	Dry ice		
MF.6	Chemicals and compressed gas	MF.6.28	Cleaning agents	MF.6.28.1	Hand soap
MF.6	Chemicals and compressed gas	MF.6.28	Cleaning agents	MF.6.28.2	Detergent
MF.6	Chemicals and compressed gas	MF.6.28	Cleaning agents	MF.6.28.3	Ammonia
MF.6	Chemicals and compressed gas	MF.6.28	Cleaning agents	MF.6.28.4	Liquid bleach (sodium hypochlorite)
MF.6	Chemicals and compressed gas	MF.6.28	Cleaning agents	MF.6.28.5	Powdered bleach (calcium hypochlorite)
MF.6	Chemicals and compressed gas	MF.6.28	Cleaning agents	MF.6.28.6	Borax
MF.6	Chemicals and compressed gas	MF.6.28	Cleaning agents	MF.6.28.7	Sodium bicarbonate
MF.6	Chemicals and compressed gas	MF.6.28	Cleaning agents	MF.6.28.8	Vinegar
MF.6	Chemicals and compressed gas	MF.6.28	Cleaning agents	MF.6.28.9	Polishes
MF.6	Chemicals and compressed gas	MF.6.28	Cleaning agents	MF.6.28.10	Carpet cleaners
MF.6	Chemicals and compressed gas	MF.6.28	Cleaning agents	MF.6.28.11	Degreasers
MF.6	Chemicals and compressed gas	MF.6.28	Cleaning agents	MF.6.28.12	Floor cleaners
MF.6	Chemicals and compressed gas	MF.6.28	Cleaning agents	MF.6.28.13	Glass cleaners
MF.6	Chemicals and compressed gas	MF.6.28	Cleaning agents	MF.6.28.14	Other cleaners
MF.6	Chemicals and compressed gas	MF.6.29	Paints		
MF.6	Chemicals and compressed gas	MF.6.30	Medication		
MF.6	Chemicals and compressed gas	MF.6.31	Semiconductor materials		

MF.6	Chemicals and compressed gas	MF.6.32	Other chemicals						
MF.7	Electronics	MF.7.1	Batteries	MF.7.1.1	Lead-acid batteries				
MF.7	Electronics	MF.7.1	Batteries	MF.7.1.2	Nickel-cadmium batteries				
MF.7	Electronics	MF.7.1	Batteries	MF.7.1.3	Mercury-containing batteries				
MF.7	Electronics	MF.7.1	Batteries	MF.7.1.4	Alkaline batteries				
MF.7	Electronics	MF.7.1	Batteries	MF.7.1.5	Other-lithium or lithium ion batteries				
MF.7	Electronics	MF.7.1	Batteries	MF.7.1.6	Other batteries				
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.1	CRT or flat screen				
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.2	Fridges and freezers				
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.3	White goods (e.g., washing machines, dishwashers, and tumble triers) with hazardous components				
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.4	Small household appliances (toasters, coffee makers, hairdryers)				
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.5	Information technology and telecommunication equipment	MF.7.2.5.1	Desktops		
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.5	Information technology and telecommunication equipment	MF.7.2.5.2	Laptops		
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.5	Information technology and telecommunication equipment	MF.7.2.5.3	Mobile phones		
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.5	Information technology and telecommunication equipment	MF.7.2.5.4	Tablets		
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.5	Information technology and telecommunication equipment	MF.7.2.5.5	Printers		
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.5	Information technology and telecommunication equipment	MF.7.2.5.6	Photocopiers		
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.5	Information technology and telecommunication equipment	MF.7.2.5.7	Servers		
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.5	Information technology and	MF.7.2.5.8	Computer components	MF.7.2.5.8.1	Hard drives

					telecommunication equipment				
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.5	Information technology and telecommunication equipment	MF.7.2.5.8	Computer components	MF.7.2.5.8.2	Solid state drives / flash memory
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.5	Information technology and telecommunication equipment	MF.7.2.5.8	Computer components	MF.7.2.5.8.3	Graphics cards
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.5	Information technology and telecommunication equipment	MF.7.2.5.8	Computer components	MF.7.2.5.8.4	Network cards
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.5	Information technology and telecommunication equipment	MF.7.2.5.8	Computer components	MF.7.2.5.8.5	Chassis
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.5	Information technology and telecommunication equipment	MF.7.2.5.8	Computer components	MF.7.2.5.8.6	Power Supply
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.5	Information technology and telecommunication equipment	MF.7.2.5.8	Computer components	MF.7.2.5.8.7	Central Processing Unit (CPU)
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.5	Information technology and telecommunication equipment	MF.7.2.5.8	Computer components	MF.7.2.5.8.8	Printed Circuit Board
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.5	Information technology and telecommunication equipment	MF.7.2.5.9	Computer peripherals (keyboard, mouse)		
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.5	Information technology and telecommunication equipment	MF.7.2.5.10	VOIP phones		
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.5	Information technology and telecommunication equipment	MF.7.2.5.11	Projectors		
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.5	Information technology and telecommunication equipment	MF.7.2.5.12	Other IT		
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.6	Consumer electronics (stereos, electric toothbrushes, digital camera)				

MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.7	Lighting equipment	MF.7.2.7.1	Incandescent Lamps
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.7	Lighting equipment	MF.7.2.7.2	Compact Fluorescent Lamps (CFL)
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.7	Lighting equipment	MF.7.2.7.3	Halogen Lamps
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.7	Lighting equipment	MF.7.2.7.4	LED Lamps
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.7	Lighting equipment	MF.7.2.7.5	Fluorescent Tube
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.8	Electrical and electronic tools (handheld drills, saws, screwdrivers)		
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.9	Toys, leisure and sports equipment		
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.10	Medical equipment systems		
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.11	Monitoring and control instruments		
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.12	Automatic dispensers		
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.13	Miscellaneous lab equipment		
MF.7	Electronics	MF.7.2	Electronic Products	MF.7.2.14	Other electronic products		
MF.7	Electronics	MF.7.3	Electronic Hardware	MF.7.3.1	Diodes		
MF.7	Electronics	MF.7.3	Electronic Hardware	MF.7.3.2	Capacitors		
MF.7	Electronics	MF.7.3	Electronic Hardware	MF.7.3.3	Electrical Relays		
MF.7	Electronics	MF.7.3	Electronic Hardware	MF.7.3.4	Electrical Connectors		
MF.7	Electronics	MF.7.3	Electronic Hardware	MF.7.3.5	Electrical Cables		
MF.7	Electronics	MF.7.3	Electronic Hardware	MF.7.3.6	Fuses		
MF.7	Electronics	MF.7.3	Electronic Hardware	MF.7.3.7	Resistors		
MF.7	Electronics	MF.7.3	Electronic Hardware	MF.7.3.8	Terminal Blocks		
MF.7	Electronics	MF.7.3	Electronic Hardware	MF.7.3.9	Other electronic hardware		
MF.8	Other products	MF.8.1	Multilayer packaging				
MF.8	Other products	MF.8.2	Composites and foams	MF.8.2.1	Carbon fiber reinforced polymer (CFRP)		
MF.8	Other products	MF.8.2	Composites and foams	MF.8.2.2	Glass fiber reinforced polymer (GFRP)		
MF.8	Other products	MF.8.2	Composites and foams	MF.8.2.3	Sheet molding compound		

MF.8	Other products	MF.8.2	Composites and foams	MF.8.2.4	Bulk molding compound
MF.8	Other products	MF.8.2	Composites and foams	MF.8.2.5	Furan-based composites
MF.8	Other products	MF.8.2	Composites and foams	MF.8.2.6	Rigid polymer foam
MF.8	Other products	MF.8.2	Composites and foams	MF.8.2.7	Flexible polymer foam
MF.8	Other products	MF.8.3	Adhesives		
MF.8	Other products	MF.8.4	Printer ink or toner		
MF.8	Other products	MF.8.5	Wax		
MF.8	Other products	MF.8.6	Waste for final treatment and disposal		
MF.8	Other products	MF.8.7	Unknown material		

2. Purchase Records

The categorization of purchase subcategories into three larger categories: goods within study scope, services (or non-goods purchases), and goods outside of study scope. All analyses in the thesis only include goods within the study scope, and exclude the latter two categories.

GOODS WITHIN THE STUDY SCOPE	SERVICES (OR NON-GOODS PURCHASES)	GOODS OUTSIDE OF STUDY SCOPE
Adhesives, Sealants & Tape	Accounting & Auditing	Architectural & Interior Design Services
Audio Visual Supplies & Services	Airfare	Building Construction & Repair
Books	Auto Rental	Fuel (Oil & Gas)
Catering	Benefits Administration	HVAC
Chemicals, Reagents, & Gases	Charitable Contributions	Natural Gas
Dining & Vending	Clinic Doctors	Plumbing
Drugs & Pharmaceuticals	Computational Services	
Electrical Components	Corporate Insurance	
Equipment Acquisition	Creative Services	
Event Planning Services	Data Storage & Management	
Event Signage/Banners	Database Developer	
Finishing/Binding Services	Design Services	
Fleet - Vehicles Acquisition	Diagnostic Services	
Flooring & Carpeting	Document Management & Shredding	
Flowers, Gifts & Misc	Dues/Fees	
General Hardware	Electrical Services	
General Industrial Supplies	Electricity	
Hw Purchase / Maintenance	Electronic Payment Processing	
Inter-University	Electronic Security	
Janitorial Services	Elevator/Escalator Services	
Janitorial Supplies	Employee Insurance & Benefits	
Laboratory Equipment	Employee Payroll & Taxes	
Laboratory Equipment Maintenance & Repair	Engineering Services	
Laboratory Supplies	Equipment Maintenance & Repair	
Material Handling Equipment	Equipment Rental	

Meals & Entertainment	Executive Search	
Mechanical Components & Services	External Lab Services	
Medical Supplies & Equipment	Facility/Property Rent	
Office Equipment	Financial Consulting	
Office Furniture	Financial Research	
Office Supplies	Fleet - Vehicle Rental	
Pest Control	Fleet Management	
Postage & Postage Equipment	General Consulting	
Printers	General Travel Expenses	
Prizes & Awards	Ground Transportation	
Promotional	Hotel & Conference Center	
Reprints/Copyrights	Inspection Services	
Research Specimens	Interest/Debt Payments	
Rfid Equipment	Internal Transfer	
Safety Supplies	IT Consulting	
Servers & Networking Equipment	Landscaping & Snow Removal	
Shipping Supplies	Legal Services	
Student Recreation Equipment & Services	Locksmith	
Telecommunications Equipment	Medical Services	
Test Instruments	Mileage Reimbursement	
Uniforms & Uniform Laundry	Mktg & Comm Services	
Vehicle Maintenance & Parts	Other Publishing Services	
	Other Student Services	
	Parking Management	
	Parking, Tickets & Tolls	
	Patent & Copyright Legal Services	
	Photography Services	
	Relocation Services	
	Royalties	
	Security Personnel	
	Subrecipient Agreement	
	Subscriptions	
	SW Purchase / Maintenance	
	Taxes & Fees	
	Temporary Labor	
	Training	
	Translation Services	
	Uncategorized	
	Union Dues	

	Video Services	
	Voice & Data Services	
	Waste Disposal	
	Water & Sewer	
	Web Development	
	Wireless	
	Writing Services	

3. Property Data – Stock Analysis

The average lifetime (time period while registered as "active") of products tagged by the Property Office.

Standard Product Name	General Category (Categorized by Rachel speaking with Property Office)	Avg. Age (Years)	Std. dev. of Age (Years)
COMPUTER, LAPTOP	Electronics	4.9	2.6
COMPUTER (desktop computer)	Electronics	6.3	3.5
COMPUTER SYSTEM, MICRO (desktop computer)	Electronics	7.8	2.9
SERVER, EDP	Electronics	6.4	2.7
COMPUTER, MICRO (desktop computer)	Electronics	5.2	2.5
PRINTER, EDP	Electronics	10.1	3.9
MONITOR, EDP	Electronics	9.0	4.2
UPGRADE, EDP	N/A	8.6	4.2
POWER SUPPLY	Lab Equipment	17.4	6.9
THERMAL CYCLER	Lab Equipment	4.5	3.8
PROJECTOR, EDP	Electronics	9.0	3.7
FREEZER	Lab Equipment	5.6	5.9
COPIER	Electronics	7.9	3.3
OSCILLOSCOPE	Lab Equipment	22.1	7.4
COMPUTER SYSTEM, LAPTOP	Electronics	4.7	2.2
PART OF, EDP	N/A	6.7	3.4
PART OF, LAB & SCI	N/A	9.1	5.8
SWITCH (network, server room)	Electronics	7.1	3.8
DESK	Furniture	16.5	5.4
FILE (file cabinets)	Furniture	17.8	5.5
INCUBATOR	Lab Equipment	7.9	8.0
PUMP	Lab Equipment	13.5	8.6
TABLE	Furniture	13.9	6.6
CENTRIFUGE	Lab Equipment	9.0	9.7
UPGRADE, LAB	N/A	11.0	6.7
REFRIGERATOR, LAB	Lab Equipment	6.1	6.9
PRINTER	Electronics	7.2	2.9
MICROSCOPE	Lab Equipment	14.1	9.9
CHAIR	Furniture	14.5	4.6
ANALYZER	Lab Equipment	11.7	8.4
TELEVISION	Electronics	4.8	4.2
CAMERA (mostly lab imaging)	Lab Equipment	10.8	6.1
DISK DRIVE	Electronics	13.9	3.8
PLUG-IN, MEMORY (RAM, etc)	Electronics	18.4	1.4
PIPETTER	Lab Equipment	2.9	1.8

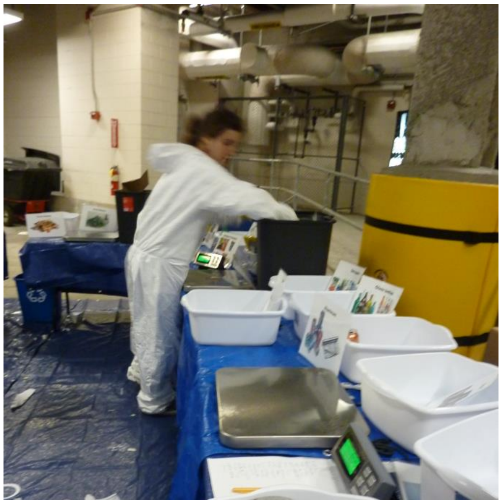
FACSIMILE MACHINE	Electronics	10.5	3.9
CONTROLLER	Lab Equipment	16.5	9.1
CENTRIFUGE, MICRO	Lab Equipment	11.6	6.8
EXERCISER (fitness gym machines)	Other Equipment	9.9	5.0
PUMP, VACUUM	Lab Equipment	13.9	6.9
AMPLIFIER	Electronics	14.1	7.8
COMPUTER SYSTEM	Electronics	7.5	4.1
TAPE DRIVE	Electronics	13.0	3.8
DISPENSER	Lab Equipment	2.9	2.8
BALANCE	Lab Equipment	14.7	10.7
LASER	Lab Equipment	14.2	7.5
HARD DISK	Electronics	11.3	4.3
SOFA	Furniture	13.3	6.3
TABLET, DATA	Electronics	6.3	2.5
SCANNER	Electronics	9.2	6.0
SPECTROPHOTOMETER	Lab Equipment	12.0	6.5
SCANNER, EDP	Electronics	10.2	4.4
METER	Lab Equipment	15.4	8.2
OVEN	Lab Equipment	12.5	8.7
SHAKER	Lab Equipment	9.7	8.9
CAMCORDER	Electronics	9.6	4.1
NETWORK LINK	Electronics	10.3	3.4
PART OF, SERVICE	N/A	16.6	10.5
READER	Electronics	3.4	2.6
SWITCH (for internet network)	Electronics	8.6	4.1
BATH, WATER	Lab Equipment	8.3	7.4
CABINET, LAB	Furniture	12.0	7.5
MONITOR, VIDEO	Electronics	14.4	6.2
VEHICLE, CAR	Automobile	11.1	5.3
PCB (printed circuit boards)	Electronics	16.1	5.5
RACK, EDP	Furniture	7.6	5.3
CENTRIFUGE W-ROTORS	Lab Equipment	7.0	7.0
SENSOR	Lab Equipment	9.8	7.0
DETECTOR	Lab Equipment	17.0	8.7
PROJECTOR, OVERHEAD	Electronics	13.4	6.3
CAMERA, CCD	Lab Equipment	13.6	4.9
MODULE	Lab Equipment	5.2	5.9
ARRAY PROCESSING SYSTEM	Lab Equipment	7.1	3.6
CABINET, OFFICE	Furniture	15.9	8.5
MEMORY	Electronics	16.3	7.1
RECORDER	Lab Equipment	18.7	7.2
SPECTROMETER	Lab Equipment	12.1	6.3
CONTROLLER, TEMPERATURE	Lab Equipment	15.7	4.3
POWER SUPPLY, EDP	Electronics	13.2	4.3

MODULE, EDP	Electronics	15.4	11.6
PROBE	Lab Equipment	14.0	8.8
POS DEVICE (credit card machine)	Electronics	5.3	2.4
VALVE	Lab Equipment	16.0	7.1
BLOCKER	Lab Equipment	4.7	3.1
PROJECTOR, VIDEO	Electronics	7.4	2.8
DEWAR	Lab Equipment	17.0	6.5
MIXER	Lab Equipment	11.9	8.4
ENCODER	Lab Equipment	24.5	8.5
NETWORK SYSTEM	Electronics	3.1	3.9
GENERATOR, FUNCTION	Lab Equipment	14.9	6.8
UPGRADE, SERVICE	N/A	5.1	6.7
LASER SYSTEM	Lab Equipment	15.1	6.1
PUMP, TURBOMOLECULAR	Lab Equipment	15.5	5.8
STACKER	Lab Equipment	3.4	1.5
VIDEO TELECONFERENCING SYSTEM	Electronics	8.1	3.1
MOTOR	Lab Equipment	13.7	6.6
PLUG-IN (to analyzer)	Lab Equipment	19.8	9.9
BATH, CIRCULATING	Lab Equipment	18.5	6.9
CIRCULATOR	Lab Equipment	14.0	10.1
ICE MAKER	Lab Equipment	10.0	4.8
MONITOR, LAB	Lab Equipment	9.0	5.8
ROTOR	Lab Equipment	10.6	7.3
FURNACE	Lab Equipment	16.3	7.1
LIQUID HANDLING STATION	Lab Equipment	1.8	0.3
DIGITIZER	Lab Equipment	22.3	10.3
MICROSCOPE SYSTEM	Lab Equipment	10.0	5.4
BENCH, LAB	Furniture	5.1	5.1
COLUMN	Lab Equipment	12.7	5.4
LENS	Lab Equipment	14.0	6.6
ROBOTIC DEVICE	Lab Equipment	6.7	5.5
ANALYZER, LOGIC	Electronics	19.8	3.7
DATA ACQUISITION DEVICE (same as data acquisition system)	Lab Equipment	10.0	2.9
RECEIVER	Lab Equipment	11.2	4.2
TABLE, LAB	Furniture	6.5	5.2
TELEVISION SYSTEM	Electronics	13.2	1.8
VIDEO CASSETTE RECORDER	Electronics	17.4	5.8
CART, SERVICE	Furniture	5.9	4.3
CHROMATOGRAPHIC SYSTEM	Lab Equipment	10.6	8.3
DATA ACQUISITION SYSTEM	Lab Equipment	9.3	6.5
GENERATOR	Lab Equipment	13.3	7.5
SAMPLER	Lab Equipment	10.6	9.1
VACUUM SYSTEM	Lab Equipment	10.2	8.2

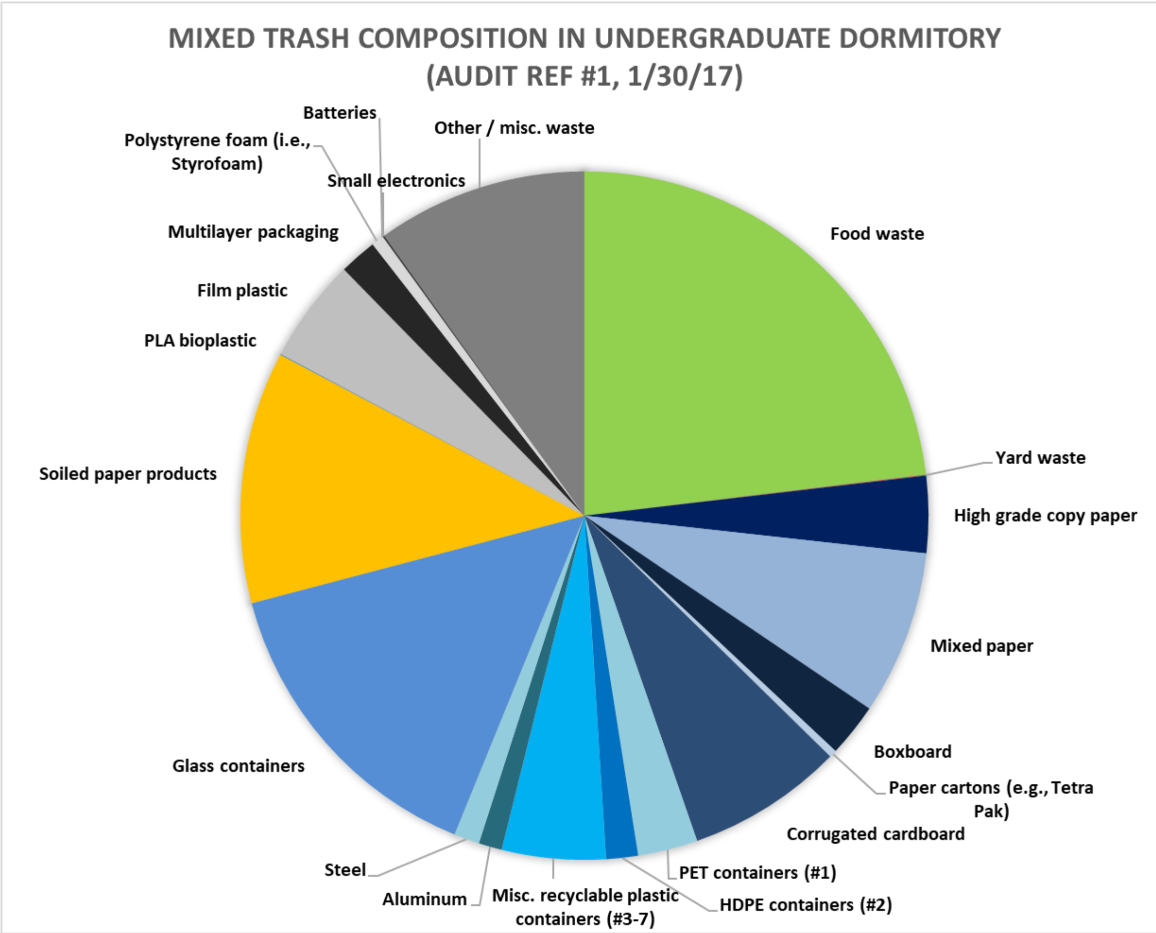
4. Waste Audits

Photos of the waste audit station set-up and bins at various locations:

Photos of the waste audit sorting process:



Photos of the waste audit weighing process:

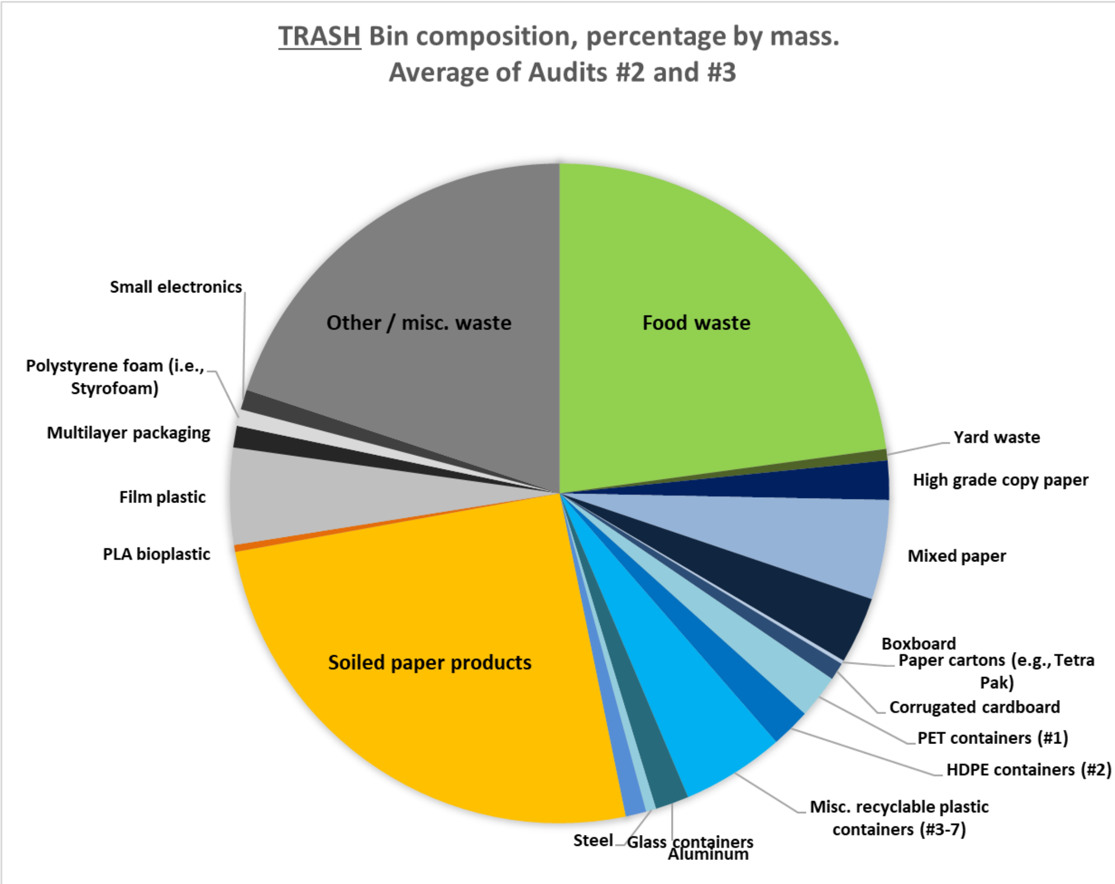


Notable elements about the audit from the undergraduate dormitory (Audit #1):

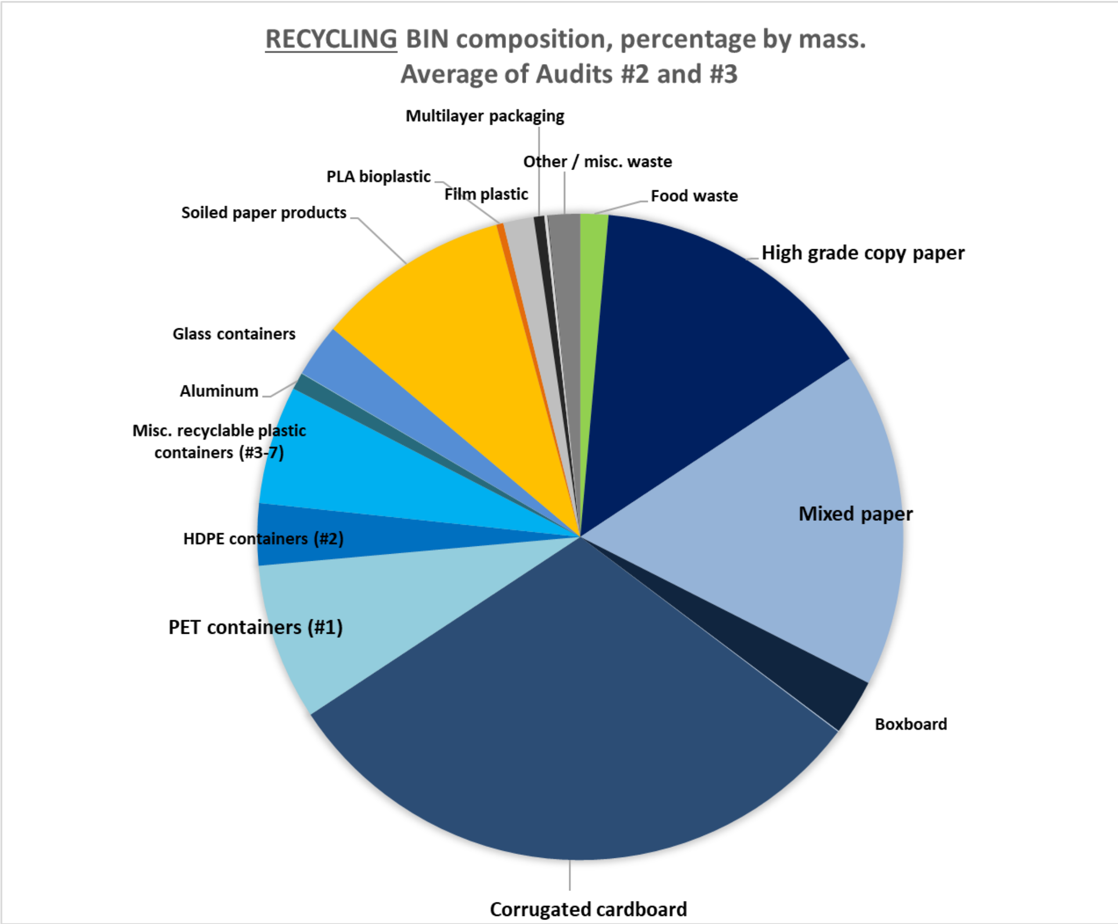
- Food waste (23%) substantial in the waste stream
- Soiled paper was mostly paper towels
- At this point in time, almost half of the waste (blue colored pie-chart wedges) sampled was recyclable in single stream recycling, but was going to trash

Waste composition from Audit #2 (8/23/2016) and Audit #3 (6/30/2016).

Material Categories	TRASH BIN		RECYCLING BIN	
	Audit #2 TRASH Bin	**Audit #3 TRASH Bin**	**Audit #2 RECYCLING Bin**	**Audit #3 RECYCLING Bin**
Food waste	33.40%	12.29%	2.65%	0.15%
Yard waste	0%	1.11%	0%	0%
High grade copy paper	2.13%	1.70%	18.24%	10.37%
Mixed paper	3.71%	6.04%	21.63%	11.89%
Boxboard	0.73%	5.82%	2.65%	2.92%
Paper cartons (e.g., Tetra Pak)	0.32%	0.03%	0.00%	0.10%
Corrugated cardboard	0.58%	1.15%	6.28%	54.59%
PET containers (#1)	2.25%	2.01%	13.68%	2.00%
HDPE containers (#2)	0.32%	3.56%	2.16%	4.04%
Misc. recyclable plastic containers (#3-7)	6.67%	3.41%	7.70%	4.12%
Aluminum	2.40%	0.90%	1.42%	0.28%
Steel	0%	0.99%	0%	0.05%
Glass containers	0.79%	1.24%	0.64%	4.69%
Soiled paper products	32.83%	17.91%	17.70%	1.66%
PLA bioplastic	0.53%	0.15%	0.69%	0.02%
Film plastic	1.81%	7.65%	1.86%	1.19%
Multilayer packaging	1.32%	0.81%	0.78%	0.28%
Polystyrene foam (i.e., Styrofoam)	0.03%	1.55%	0.05%	0.25%
Batteries	0.03%	0.02%	0%	0%
Small electronics	1.84%	0.12%	0.10%	0%
Other / misc. waste	8.31%	31.52%	1.77%	1.40%



Average composition of the trash bin contents in the academic part of campus. High quantity of soiled paper from paper towels, to-go-lunch containers, paper coffee cups.



To obtain our best estimate of the average composition of the campus' single stream recycling bin contents, we took an average of the recycling bin audits from audits #2, 3, 4, and 5. These recycling audit results may skew slightly toward the recycling composition found in kitchen, dining, and eating areas.

Recycling Audits used to determine average campus recycling composition

WASTE STREAM	Scientific research buildings Recycling (6/30/16)	Business school Area Recycling (8/23/16)	Café Front Of The House Recycling (8/22/2017)	Cafe Kitchen Recycling (8/22/2017)	Undergrad Dormitory Kitchen Recycling (5/18/2017)	**Average Composition Of Recycling**
FOOD WASTE	0.15%	2.65%	13.96%	2.65%	0.00%	3.9%
YARD WASTE	0.00%	0.00%	0.00%	0.00%	0.00%	0.0%
HIGH GRADE OFFICE PAPER	7.32%	18.24%	0.00%	0.00%	0.00%	5.1%
MIXED PAPER	12.29%	21.63%	11.04%	3.79%	0.00%	9.7%
BOXBOARD	3.02%	2.65%	1.30%	0.00%	2.72%	1.9%
TETRAPACK	0.10%	0.00%	0.00%	0.00%	0.00%	0.0%
CARDBOARD	56.45%	6.28%	8.77%	38.26%	2.33%	22.4%
PET BOTTLES (#1)	2.07%	13.68%	2.27%	3.41%	78.50%	20.0%
HDPE CONTAINERS (#2)	4.18%	2.16%	12.99%	1.52%	4.15%	5.0%
MISC. PLASTICS (#3-7)	4.26%	7.70%	11.04%	4.92%	0.00%	5.6%
ALUMINUM	0.28%	1.42%	19.48%	0.76%	0.00%	4.4%
STEEL	0.05%	0.00%	0.00%	0.00%	2.07%	0.4%
GLASS BOTTLES	4.85%	0.64%	0.00%	2.27%	7.25%	3.0%
SOILED PAPER	1.72%	17.70%	8.44%	6.82%	0.00%	6.9%
FILM PLASTIC	1.23%	1.86%	0.97%	16.29%	2.59%	4.6%
MULTILAYER PACKAGING	0.29%	0.78%	0.00%	0.00%	0.39%	0.3%
STYROFOAM	0.25%	0.05%	0.97%	15.15%	0.00%	3.3%
BATTERIES	0.00%	0.00%	0.00%	0.00%	0.00%	0.0%
SMALL ELECTRONICS	0.00%	0.10%	0.00%	0.00%	0.00%	0.0%
OTHER WASTE	1.45%	1.77%	0.97%	0.00%	0.00%	0.8%
PLA "PLASTIC"	0.02%	0.69%	7.79%	4.17%	0.00%	2.5%

5. Greenhouse Gas Estimates from Purchased Goods

Purchase Category	FY2016 Spend2	Spend in 2007 Dollars2	Multiplication factor to account for adjusting the GHG for producer to the GHG for puchaser - university spend is a purchaser - (based on ratio of EIOLCA purchaser ghg / producer ghg)	Relevant USEEIO code	GWP per dollar from USEEIO (kg co2/dollar)	Assumed region	Emission Factor Adjustment to account for region of origin	GWP in MT CO2-eq
Laboratory Supplies	$ 33,800,000	$ 28,900,000	0.83	Plastics; at manufacturer - US	1.12119	US	1.00	26,758
HW Purchase / Maintenance	$ 31,900,000	$ 27,300,000	0.97	Computers; at manufacturer - US	0.14585	China (60% of importe	1.78	6,860
Laboratory Equipment	$ 25,500,000	$ 21,800,000	1.01	Analytical laboratory instruments; at manufacturer - US	0.22847	US	1.00	4,997
Chemicals, Reagents, & Gases	$ 16,900,000	$ 14,500,000	0.94	Chemicals (except basic chemicals, agrichemicals, polymers, paints, pharma	0.70929	US	1.00	9,655
Office Furniture	$ 13,500,000	$ 11,600,000	0.95	Institutional furniture; at manufacturer - US	0.43554	China	1.78	8,442
Catering	$ 12,600,000	$ 10,800,000	1.00	Limited-service restaurants - US	0.33377	US	1.00	3,589
Drugs & Pharmaceuticals	$ 9,600,000	$ 8,200,000	0.90	Pharmaceutical products (pills, powders, solutions, etc.); at manufacturer -	0.18626	US	1.00	1,371
Meals & Entertainment	$ 5,900,000	$ 5,100,000	1.00	Limited-service restaurants - US	0.33377	US	1.00	1,671
Electrical Components	$ 4,500,000	$ 3,800,000	0.99	Electronic capacitors, resistors, coils, transformers, connectors and other co	0.29745	China	1.78	1,978
Audio Visual Supplies & Services	$ 3,700,000	$ 3,200,000	0.81	Audio and video equipment; at manufacturer - US	0.22474	China	1.78	1,022
Office Supplies	$ 3,400,000	$ 2,900,000	0.73	Office supplies (not paper); at manufacturer - US	0.3571	US	1.00	739
General Industrial Supplies	$ 3,100,000	$ 2,600,000	0.98	Printed circuit and electronic assembly; at manufacturer - US	0.29079	China / Hong Kong	1.78	1,303
Research Specimens	$ 3,100,000	$ 2,600,000	0.95	Animal farms and aquaculture ponds (except cattle and poultry) - US	1.47898	US	1.00	3,605
Dining & Vending	$ 2,700,000	$ 2,300,000	1.00	Limited-service restaurants - US	0.33377	US	1.00	752
Promotional	$ 1,900,000	$ 1,600,000	0.99	Books, newspapers, magazines, and other print media; at manufacturer - U	0.47177	US	1.00	740
Medical Supplies & Equipment	$ 1,500,000	$ 1,300,000	1.01	Analytical laboratory instruments; at manufacturer - US	0.22847	US	1.00	279
Mechanical Components & Services	$ 1,500,000	$ 1,300,000	0.94	Custom metal rolls; at manufacturer - US	0.94079	US	1.00	1,060
Event Planning Services	$ 1,200,000	$ 1,100,000	1.00	Limited-service restaurants - US	0.33377	US	1.00	337
Student Recreation Equipment & Services	$ 1,200,000	$ 1,100,000	0.74	Sporting and athletic goods; at manufacturer - US	0.35553	US	1.00	263
Books	$ 1,200,000	$ 1,000,000	0.88	Books; at publisher - US	0.08436	US	1.00	71
Computational Services	$ 1,000,000	$ 900,000	0.94	Computer storage device readers; at manufacturer - US	0.17039	China (60% of importe	1.78	230
Test Instruments	$ 1,000,000	$ 800,000	1.01	Analytical laboratory instruments; at manufacturer - US	0.22847	US	1.00	182
Flooring & Carpeting	$ 900,000	$ 700,000	0.63	Carpets and rugs; at manufacturer - US	0.75142	US	1.00	327
Janitorial Supplies	$ 800,000	$ 700,000	0.70	Soap and cleaning compounds; at manufacturer - US	0.53816	US	1.00	244
Office Equipment	$ 800,000	$ 600,000	0.91	Computer terminals and other computer peripheral equipment; at manufac	0.25597	China / Hong Kong	1.78	248
Telecommunications Equipment	$ 700,000	$ 600,000	0.99	Telephones; at manufacturer - US	0.21886	China / Hong Kong	1.78	224
Laboratory Equipment Maintenance & Repa	$ 700,000	$ 600,000	1.01	Analytical laboratory instruments; at manufacturer - US	0.22847	US	1.00	132
Uniforms & Uniform Laundry	$ 600,000	$ 600,000	0.78	Other textiles; at manufacturer - US	0.50703	Asia excluding China	1.70	340
Equipment Acquisition	$ 500,000	$ 400,000	1.01	Analytical laboratory instruments; at manufacturer - US	0.22847	Europe / Germany	1.23	108
Finishing/Binding Services	$ 500,000	$ 400,000	0.88	Books, newspapers, magazines, and other print media; at manufacturer - U	0.47177	US	1.00	157
Fleet - Vehicles Acquisition	$ 500,000	$ 400,000	0.87	Automobiles; at manufacturer - US	0.37669	US	1.00	119
General Hardware	$ 400,000	$ 400,000	0.94	Metal hinges, keys, lock, and other hardware; at manufacturer - US	0.41007	US	1.00	119
Material Handling Equipment	$ 400,000	$ 300,000	0.94	Metal hinges, keys, lock, and other hardware; at manufacturer - US	0.41007	US	1.00	112
Printers	$ 400,000	$ 300,000	0.99	Computer terminals and other computer peripheral equipment; at manufac	0.25597	China / Hong Kong	1.78	125
Flowers, Gifts & Misc	$ 300,000	$ 300,000	0.69	Greenhouse crops, mushrooms, nurseries, and flowers; at farm - US	1.08714	US	1.00	189
Creative Services	$ 300,000	$ 300,000	0.88	Books, newspapers, magazines, and other print media; at manufacturer - U	0.47177	US	1.00	90
Servers & Networking Equipment	$ 300,000	$ 200,000	0.97	Computers; at manufacturer - US	0.14585	China / Hong Kong	1.78	48
Janitorial Services	$ 300,000	$ 200,000	0.70	Soap and cleaning compounds; at manufacturer - US	0.53816	US	1.00	71
Event Signage/Banners	$ 200,000	$ 200,000	0.88	Books, newspapers, magazines, and other print media; at manufacturer - U	0.47177	US	1.00	61
Inter-University	$ 200,000	$ 200,000	1.00	Limited-service restaurants - US	0.33377	US	1.00	37
Prizes & Awards	$ 100,000	$ 100,000	0.99	Books, newspapers, magazines, and other print media; at manufacturer - U	0.47177	US	1.00	30
Shipping Supplies	$ 100,000	$ 100,000	0.97	Cardboard; at manufacturer - US	1.28247	US	1.00	75
Safety Supplies	$ 100,000	$ 100,000	0.59	Other textiles; at manufacturer - US	0.50703	China	1.78	23
Adhesives, Sealants & Tape	$ 100,000	$ 100,000	0.98	Adhesives; at manufacturer - US	0.88922	US	1.00	13
Pest Control	$ 100,000	$ 100,000	0.83	Other plastic products; at manufacturer - US	0.65091	US	1.00	5
RFID Equipment	$ 100,000	$ 100,000	0.91	Computer terminals and other computer peripheral equipment; at manufac	0.25597	US	1.00	2
Vehicle Maintenance & Parts	$ 100,000	$ 100,000	0.94	Automobiles; at manufacturer - US	0.37669	US	1.00	1

6. Interview Guide

Full Interview Guide Used for Interviews with Purchasers

□ Go over consent form and obtain signature
Date: _________________________ Time of Interview: _________________________

Demographic Info

Name: _____________________________________ (later anonymized)

Gender: M F

Age: ______________

Position/title/role: _____________________________________

Affiliation with department, lab, center: _____________________________________

Number of years individual has worked at MIT: ______________

Purchasing Decisions and Process

1. Do you purchase material goods for a sub-unit of MIT or all of MIT? What kinds of purchases?
   If subject needs prompting, ask about categories such as:
   - Food & beverage, or catering
   - Paper and paper products
   - Disposable cutlery
   - Office Supplies
   - Furniture and furnishings
   - Computers or other electronics
   - Laboratory supplies of equipment
   - Chemicals
   - Other? Specific

2. How often do you make a purchases?

4. What platform do you use to make these purchases? (E-Catalog, Buy to Pay, P-card, Purchase Order? Other?) What vendors/suppliers?
5. What are common items you buy? Why these items? Why specific brand/type? Where do you purchase these items from?
6. Are there cases when you specify the product you want, but then someone else makes the actual purchase? OR vice versa?
7. What is the magnitude of purchasing (in quantity and/or cost) for various categories? If you are unsure, would you be able to look up this information in your records after the interview?
8. How much freedom do you have in making a purchase decision? How much of the decision is pre-determined or influenced by others, such as your superior at work? Who influences their buying decisions? sales reps, PIs, other students, other labs?
9. When do they buy? End of fiscal year, when something breaks, when get new grant, etc?
10. What are some of the major factors you consider when selecting these types of items to purchase? Factors could include budget/cost, availability, convenience, habit, knowledge of options, durability, life-time of the product.
11. How is purchase for work/MIT different from a personal purchase you would make at home?
12. If you think back to a time you recently made a purchase, what were the steps involved in the process? (Gather details about each of the following steps)

- A need for the product is identified/there is a problem
- Product specification – brand, material, technical specifications
- Supplier search and selection – finding the appropriate vendor/store, cost
- Ordering/Purchase – method, online, delivery, proximity
- End of life – how much is known about where the product ends up; is it disposed of and how, and who makes that decision; what cost considerations are taken regarding disposal

Disposal and Conservation Considerations

13. Are you responsible for making the disposal decisions for the materials you buy at MIT? Are there instances when you have overseen the disposal of these products as part of your job at MIT?
14. What do you do with materials that you want to discard or get rid of? Are you ever unsure as to what to do with each of these products when you want to get rid of them? If you are not the one who disposes of the product, do you know what happens to the product when leaves their group/organization/MIT?
15. When making a purchase of one of these products at MIT, do you consider what happens at the end of product's life – in other words when or how it is disposed of? Why or why not do you consider how the product is handled at the end of its product lifetime?
16. How does material conservation or environmental impact factor in, if at all, to your purchase decision at MIT? If not, why does this not matter very much? If you do factor in sustainable, what specifically do you consider (might include environmental health

hazard, recyclability, product lifetime)? Do you weight these in the same way you would for a personal purchase?
17. In your life outside of work, how strongly do you feel about material conservation and recycling? Can you give me some examples?
18. At MIT, do you feel you could purchase a smaller quantity (or less frequently) of products? Do you feel you could use these products more carefully or for a longer period of time to extend the usable lifetime? What constraints do you feel inhibit you from such conservation efforts?
19. Do you ever buy used or secondhand products for MIT?

Effectiveness of Incentives/Hypotheticals/ Opinion Questions

20. What would enable you and your department/organization within MIT to eliminate excessive consumption or waste? What would best enable you to respond to incentives for materials conservation (such as buying only as much as you need, reusing, recycling)? In what ways would you personally be willing to help eliminate excess consumption or increase the amount of recycling?
21. Does MIT offer any incentives that you know of to eliminate excessive consumption or reduce waste?
22. Would you support or not support a policy in which MIT required that staff/faculty purchase a certain type of product, so that it could more easily coordinate recycling, refurbishment, and repair to extend the life of such products? What are the pros and cons of such a policy?
23. If MIT offered an online platform in which you could notify the university that you had unwanted durable goods to pick up would you use it? Why?
24. Do you have any suggestions for how MIT could help you or others make more sustainable purchasing and/or disposal decisions (lessening our materials footprint)? Are there any purchasing or disposal programs or policies you would like to see put in place at MIT?

For those who buy lab equipment

25. Would you consider buying preventative maintenance for equipment if it could extend the life? If MIT provided, would they like it? (ie. filters, coils)
26. Do you buy chemicals in bulk - how common?
27. How do you track lab inventory? Chemical Inventory System?

Debrief participant on full-picture motivation for study, and explain my interest in sustainability

"Thank you for taking the time to talk to me. As you may have observed from some of the questions, I have a specific interest in sustainability. This interview-based study is part of my larger dissertation project, which aims to understand – both quantitatively and qualitatively – what MIT as an institution purchases and disposes. I am interested in knowing the materials consumption profile so that I can carry out analyses on the environmental impact of our consumption and identify opportunities for reducing this impact. The interview portion of the research focuses on the behavioral and organizational drivers associated with consumption, which will help me better understand the full picture of how things work at MIT, and hopefully provide some insight that helps identify opportunities for improvement at the purchaser-level. I am happy to answer any questions you have. In the meantime, if you would like more information on how to make sustainable purchases (higher recycled content, less toxic, ethically manufactured), please let me know and I would be happy to email you some resources. Lastly, as a thank you for your participation, once this research is finalized, you will receive an email with my full dissertation, which will contain the anonymized results of this study."